Technical guidance for evaluating resource efficiency and circular design opportunities

Prepared for Waka Kotahi NZ Transport Agency by Beca Limited

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WAKA KOTAHI NZ TRANSPORT AGENCY

Te Kāwanatanga o Aotearoa New Zealand Government

More information

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Contents

1. Introduction

Background and purpose

Waka Kotahi NZ Transport Agency commissioned Beca Limited (Beca) to develop this supplementary technical guidance to support the *Resource efficiency guideline*. Waka Kotahi also has a resource efficiency strategy, Te Hiringa o te Taiao – Our Resource Efficiency Strategy, with a vision to use resources sustainably with minimal environmental impact. Waka Kotahi also has a Resource Efficiency Policy for Infrastructure Delivery & Maintenance that sets out requirements for implementing resource efficiency, and a suite of guidance and tools to support teams incorporating resource efficiency on their projects.

This document is part of this suite of guidance, and contains the following:

- **Section 2** presents an outline on how to use this guidance and how the prompts can be implemented on projects.
- **Section 3** provides a summary of key terminology and definitions.
- **Section 4** provides background to the circular economy.
- **Sections 5–7** contain the ***circularity prompts,*** which is the key resource of this document. The prompts can be used while evaluating resource efficiency opportunities, including questions covering all stages of the project cycle, from business case and optioneering, through to design, construction, and maintenance.

  The questions are intended to challenge the status quo and encourage project teams to look for opportunities to create long-term value. The questions can be considered during evaluation workshops, as well as during the design process when making decisions around materials or resources. Case studies of local and international project examples of circularity principles being actioned are also included.

- **Section 8** provides links to further information and resources.
- **Section 9** provides references.
- **Appendix A** provides supporting case studies.

Challenges for implementing resource efficiency

Te Hiringa o te Taiao -– Our Resource Efficiency Strategy notes the current challenges relating to resource efficiency on transport infrastructure projects which include:

- Large consumption of virgin materials:
  - In 2018 Aotearoa New Zealand generated approximately 33.7 million tonnes of aggregates, of which 22 million tonnes were used for road construction (Nelson et al, 2022).
- Low levels of recycling:
  - Recycled materials made up about 2.2% of the pavement materials used in Waka Kotahi maintenance contracts in 2019 (Waka Kotahi, 2021b).
- Large production of waste materials from construction and demolition:
  - This is putting pressure on already constrained landfill and cleanfill sites. Many of these materials have suitable properties as roading materials.
  - It is estimated that construction and demolition waste makes up approximately 40–50% of the total waste going to landfill in New Zealand (Te Waihanga, 2021).
  - New Zealand's total recovery rate for construction and demolition materials is approximately 28% (Te Waihanga, 2021).
- A need to fill knowledge and capability gaps within industry to drive a step change.

2. Implementing this guidance

Who should use this document?

This guideline is intended for use by:

- consultants, contractors, project managers and stakeholders who participate in the planning, design, construction, and maintenance of our transport networks
- Waka Kotahi staff whose work and actions affect resource efficiency.

This guidance is not only to be used by those applying the Resource Efficiency Policy but is a general resource for use by the infrastructure sector as there are benefits to applying it across council-led infrastructure projects or other infrastructure projects.

When to use this document?

Opportunities to improve resource efficiency and apply circular design principles can be found on a project at all design stages. However, the early stages of a project, such as during business case development and including optioneering, have the most potential for realising these opportunities as there is more room to make design changes, as shown in Figure 1 below.

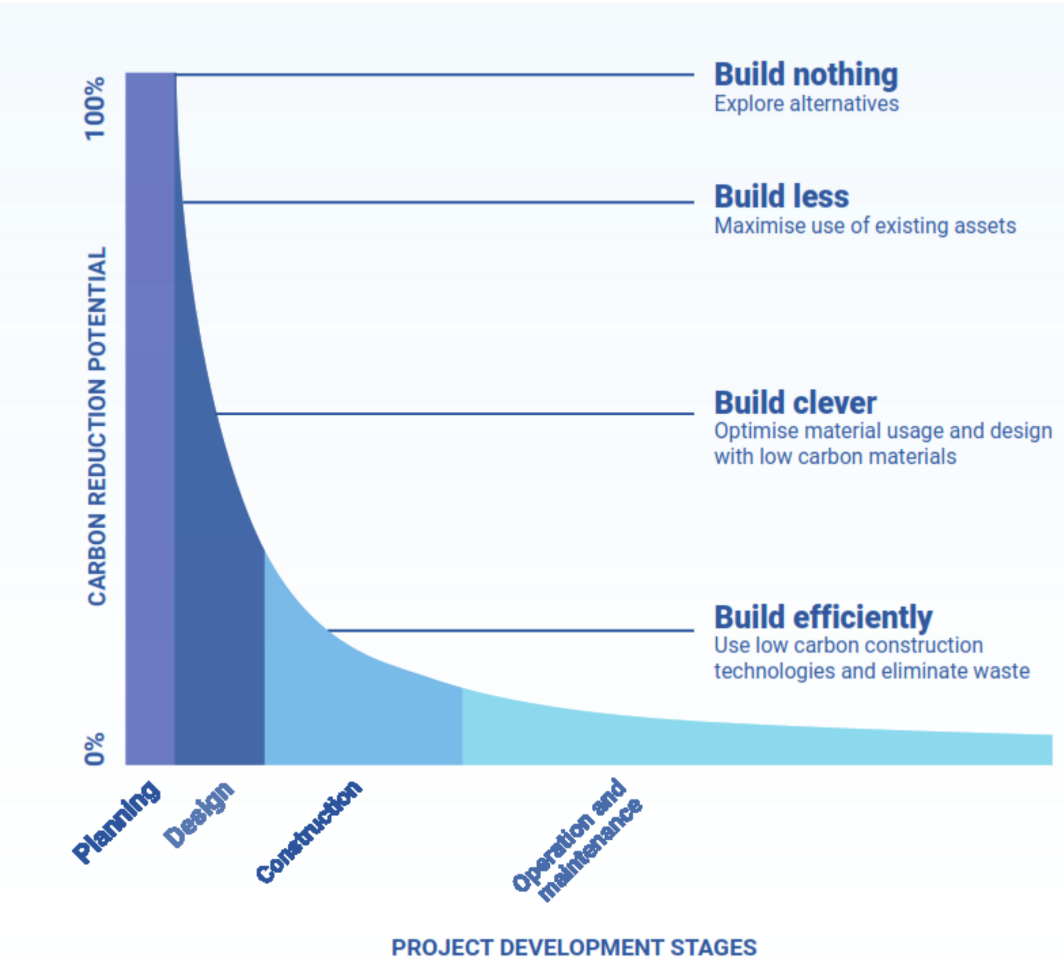

Figure 1: Carbon reduction potential at various stages of an asset's life. This shows that the vast majority of carbon reduction can be achieved in the early stages of a project's life and decreases significantly as a project goes into construction and operational phases. Adapted from: World Green Building Council, 2019.

Projects are dynamic environments. After the optioneering phases, new opportunities may arise as things change or as the design develops. To maximise resource efficiency and realise potential opportunities, circularity should be considered throughout all design stages.

During construction, there may be new opportunities as specific materials are explored and selected, and the construction methodology becomes more defined.

The maintenance phase presents an opportunity to review the performance of the asset, look for ways to extend the life of the asset, and/ or adapt the asset to suit the changing environment.

How to use this document?

The design teams can consider the ***circularity prompts*** on their project, then record the opportunities and outcomes.

Opportunities workshop

The ***circularity prompts*** in this resource can be used to support ideation during the opportunities workshop to evaluate resource efficiency during tender, design, construction, and maintenance.

Outcomes from workshops should be recorded in the opportunities register spreadsheet (refer to the *Resource efficiency guideline for infrastructure delivery and maintenance*).

Decision making during design

These ***circularity prompts*** can be referred to outside of a formal opportunities workshop when decisions are being made on the project. For instance, when deciding between two methods of bridge construction, use the prompts in section 5 and/or 6 to consider how the different options may reflect better, worse, or neutral outcomes for resource efficiency.

If it is appropriate, for example if the project is of a high capital value, there may be a formal decision-making process, such as multi-criteria assessment (MCA). These prompts can be used to help set up the decision-making process such as choosing which criteria to score against.

If the project is following an MCA process, there may be specific forms or templates which can be used to record this information.

The outcomes from decision making could also be recorded in delivery reports, if appropriate.

Case studies

Appendix A provides a list of known case studies that provide examples of how resource efficiency and circular design is being implemented in New Zealand and internationally. A number of these case studies have also been used within the document as examples. These case studies will be updated as examples are provided from current and future Waka Kotahi and other New Zealand projects.

3. Key terms and definitions

Some key terms and definitions relating to circularity are summarised in Table 1 below.

Table 1: Key terms and definitions

Term	Definition
Circular economy	A circular economy is a systems solution framework that moves our economy from a take-make-waste model into one that does not create the waste in the first place. There are three principles, including: • designing out waste and pollution • cycling materials and assets at their highest value • regenerating natural systems. For more information on the circular economy, see section 4.
Circular inflow	Inflow that is either a renewable material/resource and used at a rate in line with natural cycles of renewability or a non-virgin material (repurposed or recycled materials, second-hand products or refurbished parts).
Circular outflow	Outflow that is designed and treated in a manner that ensures products and materials have a full recovery potential and extend their economic lifetime after their technical lifetime, and is demonstrably recovered.
Cradle to cradle	A design framework that honours all future generations by designing and manufacturing for next use, instead of end of life.
Embedded impacts	The environmental and social impact of a project, from optioneering to maintenance phase.
Investment Logic Mapping (ILM)	ILM is a technique to ensure that robust discussion and thinking is done up-front, resulting in a sound problem definition, before solutions are identified and before any investment decision is made.
Linear inflow	Virgin, non-renewable resources.
Linear outflow	Outflow that is not classifiable as circular. This means that the outflow is not circular in design and/or consists of materials treated in a manner that they have no recovery potential or are neither demonstrably recovered nor flowing back into the economy.
Modular design	Design principle that calls for products to be manufactured using a set of components that can be individually replaced, preventing entire products from becoming useless.
Product-as-a-service (PaaS)	A combination of products that are accompanied by services. The product is joined by more features or service contracts to repair or replace. With PaaS, products are offered in subscription models that are offered with services attached.
Resource efficiency and waste minimisation plan (REWMP)	A REWMP is defined by Waka Kotahi as a plan that outlines actions that will be taken to reduce energy and greenhouse gas emissions, increase uptake of recycled and alternative materials, reduce use of virgin and high carbon intensity materials, reduce water consumption, and reduce waste. It is a requirement under the *P48 Specification for resource efficiency policy for infrastructure delivery and maintenance*.
Resource efficiency guideline for infrastructure delivery and maintenance and opportunities register and initiatives tracker	The *Resource efficiency guideline* enables the Resource Efficiency Policy for Infrastructure Delivery & Maintenance and *P48 Specification for resource efficiency policy for infrastructure delivery* to be implemented by outlining requirements for developing a resource efficiency and waste minimisation plan, evaluating opportunities, target setting and reporting. The Opportunities register and initiatives tracker (appendix A to the guideline) is a centralised register and a live initiatives tracker. It is a Microsoft Excel-based tool that can be downloaded from the Waka Kotahi website. It is used to support the opportunity identification and implementation process outlined in the *Resource efficiency guideline*.

4. Background to the circular economy

Our current economic model is based on a linear 'take-make-waste' approach. Raw materials are taken from the earth to make products, which are eventually decommissioned and thrown away as waste. Much of this waste ends up in landfills or incinerators and is lost. Energy is generated by finite sources, for example fossil fuels.

The challenges for resource efficiency (refer section 1) stem from the 'take-make-waste' approach. This cannot work in the long term because the resources on our planet are finite.

Maximising resource efficiency requires a shift to a system that utilises the full value of materials while they are in use, then recovers and regenerates products and materials at the end of each service life – a circular economy.

A circular economy is a closed-loop system that continuously cycles materials and products and utilises renewable energy. The difference between a linear and circular economy is shown in Figure 2.

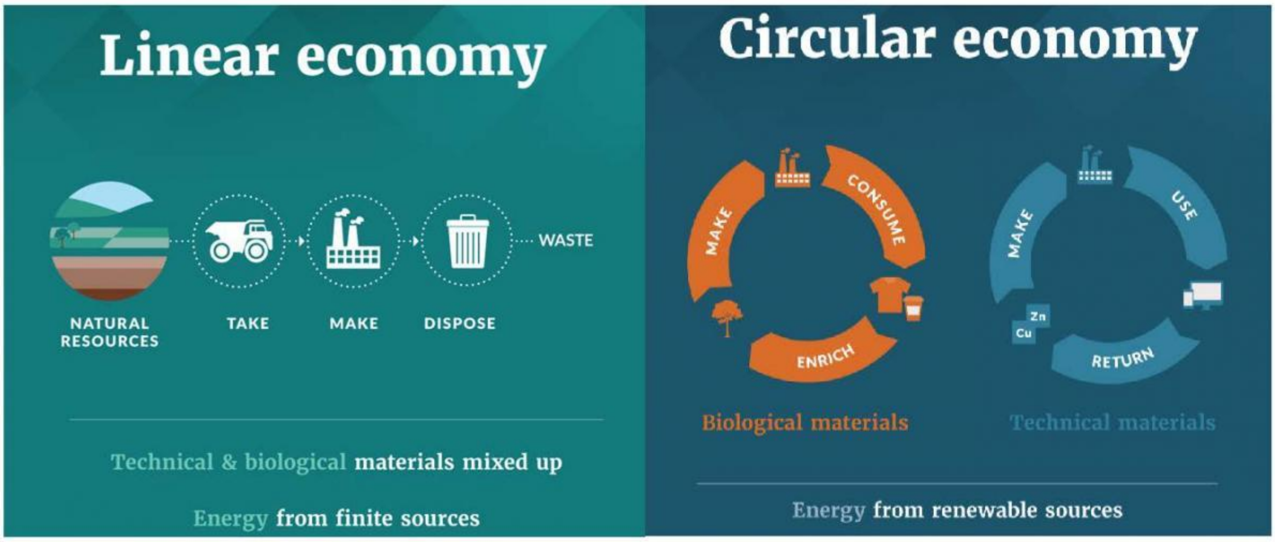

Figure 2: Linear economy versus circular economy. Adapted from Ellen MacArthur Foundation

The circular economy is based on three key principles, as shown in Figure 3:

- designing out waste and pollution
- cycling existing materials and assets to keep these in use for as long as possible
- regenerate natural systems.

Figure 3: The circular economy principles. Adapted from Ellen MacArthur Foundation

An illustration of the material flows through a company is shown in Figure 4. In this example, an assessment of the material flows will indicate how effectively a company closes the loop on circularity (World Business Council for Sustainable Development, 2022).

This approach can be applied to a project to assess the project-level circularity by analysing the following:

- **Inflow:** How circular are the resources, materials, products and parts sourced?
- **Outflow – potential recovery:** How is the project designed to ensure the technical recovery of components and materials at a functional equivalence (for example, by designing for disassembly, repairability, recyclability, etc.) or that they are biodegradable?
- **Outflow – actual recovery:** How much of the outflow is actually recovered?

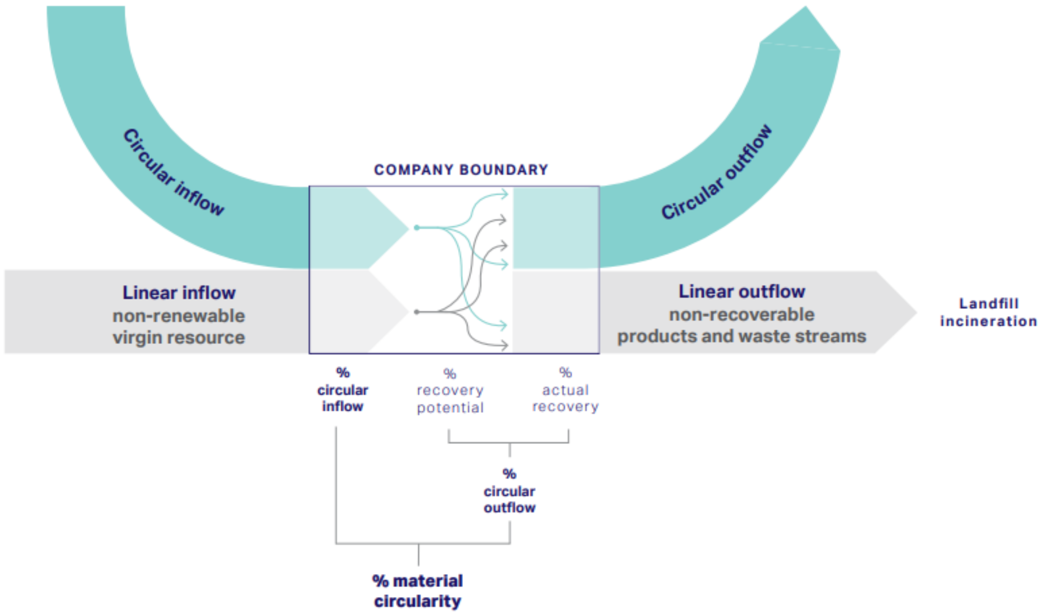

Figure 4: Illustration of material flows.
Adapted from Circular Transition Indicators, V3.0. Metrics for business, by business, (World Business Council for Sustainable Development, 2022)

5. Evaluating opportunities while optioneering

The prompts and guidance provided in this section focus on how to evaluate opportunities for resource efficiency and circularity, while in option selection through to screening or multi-criteria analysis. It is aimed at projects at programme business case (PBC), indicative business case (IBC), or single-stage business case (SSBC) phase, where multiple transport options are being considered.

For capital projects, a build nothing solution is likely to be better for resource efficiency than an upgrade or retrofit solution. An upgrade or retrofit solution is likely to be better for resource efficiency than a full, new-build solution such as developing a greenfield site.

While optioneering, it is important to put a resource efficiency lens across the different options to consider how things like materials, carbon, water, and waste will be used or produced and how they can be minimised. It is also essential to consider the whole-of-life impact of different options on resource efficiency and circularity, including the expected maintenance requirements over the life of the asset. Opportunities for resource efficiency and circularity can be considered within the scope of options or can be identified for consideration at future project phases.

It is important to note that opportunities for resource efficiency in maintenance and construction will likely be identified during early project stages, when optioneering teams may be considering low-maintenance designs. These opportunities should be carried forward throughout project delivery, to ensure they are implemented during maintenance and construction.

Build nothing

For capital projects, a build nothing solution is likely to be better for resource efficiency outcomes than a build or maintenance solution. This can only be achieved by considering alternative strategies to delivering the investment objectives, while in the early stages of decision making. In some cases, the later optioneering stage may be too late to consider a build nothing solution. Unless you are well down the path and build nothing has already been legitimately considered and ruled out, then it is always worth challenging.

- Is a build nothing solution being considered amongst the options? For example, a solution that uses the infrastructure that currently exists.
- Can the way we use existing infrastructure be changed to meet the investment objectives while significantly reducing resource use? For example, can changes to traffic signalling, reallocating lanes or re-routing traffic flows to an under-utilised road allow the investment objectives to be met?

Case study 1 – Superblocks, Barcelona

Historically, cars were the focus while designing the city of Barcelona. Approximately 60% of the public space is for cars and more than one million cars cross the city every day. Superblocks is a strategic plan for the whole city that will turn one out of three streets in the city into green streets by 2030. These are traffic-calmed streets, with priority for pedestrians, and sustainable transport such as trains, subways, trams or bikes, more greenery, and spaces for interaction, play and recreation.

A superblock is an area of urban land bounded by arterial roads; within the superblock, the local road network, if any, is designed to serve local needs only, the streets inside serving as public squares for the neighbourhood, widespread pedestrianisation and comprehensive traffic calming.

By 2024, the goal is that 80% of trips in Barcelona will be on foot, by bike or by public transport. The city has found that the superblocks reduce pollution (in Sant Antoni atmospheric pollutants such as nitrogen dioxide (NO_2) have dropped by 25%), reduce noise (in Glòries has dropped by 9 decibels), increase sales of local businesses and reduce the number of cars in the superblock area, as well as in the adjacent streets.

Build less

Designing and/or building less is likely to be a practical way to meet the investment objectives while achieving resource efficiency and circularity outcomes at the optioneering stage. During optioneering, teams should consider: How do the options maximise the use of existing assets to meet the investment criteria? Can existing assets be retrofitted, reused, or repurposed to avoid new builds? Can the extent of works be reduced but still provide the same functions? Can the works be staged with flexibility and adaptability built in to meet the needs of the future?

Options that seek to reduce the quantity of imported materials and construction required will be favoured from a resource efficiency perspective.

Case study 2 – The High Line, New York

The High Line is a railway line that runs along the west side of Manhattan. The elevated railway was used to transport millions of tons of meat, diary, and produce to the factories in Lower Manhattan. The railway fell into disuse in the late 1990s, and many people were calling it an ugly eyesore with the then mayor of New York signing a demolition order.

With strong public advocacy, the transformation into a public park was considered. Today, the High Line is one continuous, 1.45-miles-long greenway featuring more than 500 species of plants and trees. This is an example of build less, as the avoided demolition has ensured resource efficiency through re-purposing a structure, rather than using completely new materials, and sending old materials to waste.

The following questions should be considered while developing and evaluating the different solutions to meet the investment criteria:

- What is the low-build solution? A low-build solution to the investment objectives might be a combination of utilising existing assets and building new or improving current assets to make them suitable for use.
- What approach/es can be taken to minimise the quantity of new material required in the options being considered?
- What level of service is the asset being designed to and is it essential to maintain that level of service?
- What opportunities exist to retrofit or reuse our existing infrastructure? How can it be improved or modified to meet the client's needs?
- Could disassembly be considered in the design process, so materials and assets are protected when they are removed?
- Have we identified opportunities to prolong asset life and/or ensure the asset is fit for future needs (design for longevity)?
- Have we considered the future needs of the asset so that flexibility and adaptability are incorporated, and it has an ability to reconfigure or evolve as needs change? For example, a carpark that can change to a commercial use once demand has been removed.
- Have we considered the durability of materials that are required to be replaced and/or refurbished? How might these choices impact future maintenance, repair, or upgrades?

Case study 3 – Intelligent traffic management for infrastructure investment planning – Mayflower and AAEON Technology

Mayflower has partnered with AAEON Technology to help local governments and traffic management groups make road infrastructure improvement decisions. With its lightweight, easy-to-adopt optical sensor, the Mayflower Smart Control Insite Sentinel sensor can be mounted anywhere and moved as needed.

The sensors can collect real-time data to help understand traffic patterns, such as classifying vehicles, measuring traffic flow and bicycle lane usage, counting pedestrians, and tracking bike and/or pedestrian movement. The data is collected and integrated into a digital platform, which can be interrogated and analysed to help with early decision making around road infrastructure investments such as the addition or changes to traffic lanes.

- How might we avoid using, creating, or consuming while still achieving the intended project outcome?
- Are there plans in place that consider the full lifecycle of the infrastructure from operation to maintenance to end of life?
- Have potential future waste streams of this project been considered? Have we designed to maximise material circularity or their efficiency?

Case study 4 – Design for the future, the next London Bridge

Buro Happold explored options for a zero-carbon London Bridge, including reusing the piers, thus making the bridge spans the same as the existing, and also using low-carbon materials such as timber.

Current trends show an increase in cyclists, and reduction of motor vehicles, using the bridge. While a new carbon-zero London Bridge will need to meet the requirements for today, this may not always be the case in the future. A primary structure from steel could be built to meet the 120-years design life for a bridge. It could be designed with a width appropriate to the lower expected usage rates for 50 years' time. Timber extensions could be installed to provide extra width and space for the next 30 years, meeting today's demands, and reducing the overall carbon footprint.

This is an example of build less through reducing the amount of steel (by adopting timber materials where possible) and the carbon footprint, as well as creating a more appropriate and adaptable space for future use.

6. Evaluating opportunities during design

Once a solution has been chosen, the project moves on to the tender, concept, preliminary, and detailed design phase. This stage of the project presents different opportunities, at different scales, to apply circularity principles. This section provides some of the prompts for a project team to consider in the design phase to design less and design smart, while achieving the same expected outcomes.

It is important to note that opportunities for resource efficiency in maintenance and construction will likely be identified during early project stages, for example, during design phases teams may be considering low-maintenance design with more efficient material use. These opportunities should be carried forward throughout the project delivery, to ensure they are implemented during maintenance and construction.

Design less

Looking at how existing infrastructure could be retrofitted to avoid new builds, or how the design could be reduced while providing the same functions.

- Can we reduce the size and scale or the project? For example, is there an option for a shorter route?
- Are there any opportunities to optimise the existing infrastructure so that we build less (or even build nothing)?
- Are there opportunities to realign the route or change the geometry to reduce earthworks (reduces handling and construction fuel emissions)?
- What opportunities exist to retrofit or reuse the existing infrastructure? How can it be improved or modified to meet the project needs?
- Have we identified opportunities to prolong asset life/ensure asset is fit for future needs? Can we extend the design life of the project to prevent a rebuild?
- Have the waste streams (and future waste streams) on this project been identified?
- Are there opportunities to disrupt the waste stream before it becomes an issue? For example, choosing a pavement surface that allows 'mill and fill'.
- What would be needed to remove the waste completely from the project?
- Could disassembly be considered in the design process, so materials and assets are protected when they are removed? Have we selected materials or products that can be disassembled?
- Are the properties of materials specified for the project well understood, including lifecycle information, for example, can materials be recirculated? Do you have environmental product declaration (EPD) information? What percentage of the materials can be recaptured? Will the quality of the design be affected through adopting composite materials?
- Have we identified the use of materials that can be recovered and reused? Are we supporting innovation in material selection?
- Is there an understanding of the current and future operating conditions and what causes loss, damage, or defects?

Case study 5 – A century without Maintenance, Geelong's everlasting bridge

In 2017, the City of Greater Geelong applied the procurement for innovation concept to a 100-year maintenance-free bridge tender. The tender invited companies to develop solutions to the costly maintenance problem associated with traditional bridges, which cost the city roughly $500,000 to inspect, repair, maintain and replace each year.

The winning tender was for a design using a new and innovative combination of materials, which includes geopolymer, made with partly recycled materials, reinforced with carbon fibre that should ensure the bridge requires no maintenance over its 100-year lifespan. The bridge also uses concrete manufactured using fly ash as an alternative to cement. The fly ash concrete reduces corrosion due to its high alkaline composition and utilises a waste product.

- Are we specifying the reuse of material before extraction of raw/virgin materials?

Other things to consider

- Has the energy use and water use on this project been considered? Are there opportunities to optimise these?
- Are there opportunities to repair and restore the natural environment?
- How does the design allow for natural processes to continue?

Case study 6 – [Crossrail, London]
The Crossrail project, also known as the Elizabeth line, is a new underground railway line from east to west through central London, providing faster journeys. The line is expected to carry 200 million people a year and raising the rail capacity in London by 10%. The project implemented several processes to improve resource efficiency including the following:

- Design out waste workshops were carried out early in the design process with members of the design team, to identify opportunities to design out waste and influence the railway and station designs. The opportunities were scored based on their ease on implementation and potential impact to the project.
- Waste Resources Action Programme (WRAP) Net Waste Tool was used to identify the best opportunities to increase the recycled content of materials used for construction. The Net Waste Tool uses cost and quantity data from the project and uses its internal database to identify the building components that contribute the highest recycled content and provide the best opportunities to increase recycled content (known as ‘quick wins’). Through this process, Crossrail has been able to achieve an overall recycled content of 36%.
- Tier 1 contractors were required to collect and recycle water during construction and minimise water use in site accommodation. Methods included using:
    - groundwater or tunnel ingress water instead of potable (drinkable) water (for activities such as bentonite mixing, slurry dilution, grout mixing, cleaning and dust suppression)
    - closed loop or semi closed loop drainage systems where water is used (including via rainwater and runoff harvesting)
    - water efficiency measures in office and welfare accommodation
    - water footprinting and smart metering of water use for specific construction activities.

Design clever

Look for opportunities to improve resource efficiency and the impacts on the environment through designing out waste and pollution, looking for ways to utilise existing materials or assets, and exploring new and innovative solutions or materials on the project. Identify where smart data, the use of technology or future proofing can improve resource efficiency for future project phases such as construction and maintenance.

- Have new construction materials/technologies been identified that are less impactful on the environment? For example, bio-based materials.
- How might the design be more modular or adaptable? Have we explored modular design and prefabrication opportunities?
- How might the design maximise our ability to reuse, recycle, or refurbish in future?
- Have opportunities for reuse of demolition waste and/or contaminated soils within the project site, rather than landfill been considered?
- Are there opportunities to reduce the embodied carbon through design improvement?
- Does the design consider resilience for future generations?
- Have data and technology been utilised to future proof for operation and maintenance phases? For example, digital twin, material passports, end-of-life planning.
- Are there opportunities during the construction process to adopt standard sizes of construction material to minimise waste?

Other things to consider

- Has an assessment been carried out to identify the natural systems (water, nutrient, ecosystems and/or habitats) affected by this project? Are there opportunities to avoid altering the natural environment?
- Have the impacts on insects, animals, and birds through the removal of their habitat been considered? If not, how will their ecosystem be supported while the new planting establishes itself? Is there an opportunity to reintroduce species that have disappeared?
- Can the project enhance the surrounding community by giving back in the form of ecosystem services? Can this project restore wider socio-ecological systems?
- Have we incorporated green infrastructure, networks or systems including waterways, walls, roofs, ground cover and open spaces to support sustainable communities?
- Have products or systems been considered as a service, for example, take back and repair, or incentives for ongoing maintenance?

Case study 7 – Smart circular bridges

'Smart circular bridges' (SCB) are made of bio-composites – a combination of organic materials such as flax, and hemp, combined with a bio-resin. The bio-composite materials in the SCBs have about half the strength of aluminium, but the combination of this strength with its lightweight properties give bio-composites great potential for application in building and civil structures.

As well as new materials, these SCBs have a new approach to structural safety, by using a self-sensing system. This Structural Health Monitoring (SHM) system constantly monitors the structure and its material behaviour, but it also evaluates its level of structural safety using innovative and sensitive fibre optic sensors (FBGs). Real-time data is constantly collected and evaluated, giving early warnings in case pre-set material limits should be reached.

Case study 8 – Park 20/20

Park 20/20 is a 28-acre business park in the Netherlands, built on cradle-to-cradle design principles (a key component of the circular economy).

Construction materials are leased from suppliers who retain ownership and can recover and reuse materials when buildings are disassembled. In this way, Park 20/20 acts as a materials bank: the materials are 'withdrawn' at the end of life and reused again at high quality.

Energy is produced from solar panels, water is recycled, and waste is converted to biogas to provide an alternate source of energy.

Nestled among the buildings are also greenhouses and vegetable gardens used to grow organic fruit and vegetables, which are served in the on-site cafe.

7. Evaluating opportunities during construction and maintenance

During the construction and maintenance stages there are opportunities for resource efficiency in what materials are used (whether they are virgin or recycled materials), where they are sourced from, if they are used well to reduce waste, and how materials will be used in the future. Opportunities for resource efficiency can also be found in how the project is constructed, and in extending the asset life.

Important to note that opportunities for maintenance and construction stages will be identified in the design stage – low maintenance designs will be considered while optioneering, or developing the design. These opportunities should be carried forward throughout the project delivery.

Build clever

Looking for opportunities to use materials well throughout the lifecycle of the asset and reduce waste during construction.

- Are there opportunities during the construction process to adopt standard sizes of construction material to minimise waste?
- Can we use modular components (such as smaller parts rather than a large area or asset) to make things easier to replace in the future?
- Will the asset be repaired or replaced in the future? Will parts that need replacement be easily accessible and available to source in the future? Will asset use need to cease while repairs or replacements are made?
- Are there opportunities to trial and adopt alternative materials or construction techniques to improve resource efficiency? For example, low-carbon or bio-based materials?
- How might we extend the asset life without generating more waste when repairs are required?
- Are there opportunities to incorporate products as a service (PaaS)? Could the project support PaaS in the future, and do we need to specify sensors to gather data for this purpose?
- Is there an opportunity to take a precinct approach to share energy, water, materials, machinery, plant on this project?
- Can smart sensors be implemented to allow asset management data capture during future use?
- Can the parts and materials be decommissioned, deconstructed, or reworked to be used again?

Case study 9 – Waka Kotahi scour protection emergency works

Waka Kotahi required additional scour protection to prevent riverbed scour further undermining a large rock embankment at a highway site with no nearby detours. Several structural alternatives were available for the emergency works project.

The selected option was a wire-rope groyne composed of steel posts embedded within the riverbed and laced together with wire ropes. Initial sources of new materials for the steel posts were newly manufactured in Australia with shipping to New Zealand. An alternative was found by repurposing end-of-life railway track already available in the country. This approach reduced cost, avoided shipping delays, and adopted circularity principles through using non-virgin materials, while providing a similar level of performance to a new product.

Case study 10 – Circular viaduct, Netherlands

In practice, viaducts in the Netherlands hardly reach their technical lifespan and are demolished much earlier for functional reasons. This led to the project leader at van Hattum en Blankevoort (vHeB), challenging the team before getting started with the construction of a new viaduct: Why not make it circular?

The prototype is a 20m-long bridge which is modular, scalable, de/re-mountable, and therefore fully re-usable solution. More specifically, a demountable bridge deck, working with prestressing without attachment and 'shear keys'. On 4 December 2018, five girders arrived at the Kampen site. Thirty-two bars were fixed though the girders. The main contractor was the first to successfully cross the viaduct in his car, followed by a large convoy of trucks and road vehicles.

At the beginning of September 2019, the circular viaduct was dismantled successfully and without damage in its original five girders. After being transported to a temporary storage facility at Consolis Spanbeton, one of those was also disassembled into the eight concrete elements that form a girder for further examination. With this step successfully completed, the viaduct awaits a new destination where it will be re-assembled.

Case study 11 – Bailey bridges

A Bailey bridge is used to provide temporary connection while a damaged bridge is repaired or rebuilt. The structure is a prefabricated single-lane bridge that can be installed relatively quickly. Bailey bridges have been used around the world for the past 80 years with some of the most common uses in New Zealand being:

- replacing collapsed bridges
- restoring access to roads washed out in storms
- providing a cost-effective temporary structure for roading projects
- providing minor stream crossing for movie locations and other non-emergency situations.

The basic component of a Bailey bridge is a 3-metre-long truss panel, which can be configured to provide longer spans if necessary. A Bailey bridge is a good example of a temporary structure which can be reused and reassembled several times in various situations.

Build efficiently

Utilising low-carbon construction technologies, including digital platforms, and eliminating waste.

- How can the asset life be extended without generating more waste when repairs are required?
- Can digital tools or models be used to optimise construction, for example earthworks volumes or plant movements?
- Are there opportunities for plant and machinery to operate using renewable energy?
- Is there a system for reporting and monitoring the waste to landfill, and what has been diverted on site? Are there targets the project needs to achieve?
- What percentage of materials are expected to be reused, recovered, or recycled? How will these be monitored during construction?
- Are there opportunities to use local suppliers to reduce transportation distances of materials, staff, and/or plant to the site?
- Are there opportunities to harvest materials from other projects?

- Do we understand the operating conditions and what causes loss, damage, or defects? This will help to create a strategy for an optimised environment.
- Have the materials flows been mapped to understand each iteration of a material's lifecycle for re-use and what percentage can be recaptured? Is there a loss in quality if using composite materials?

Other things to consider

- Has water use, collection and discharge and the interaction with the natural system been considered? Could the grey water be used for a process in order to increase circularity?

Case study 12 – Takitimu North Link project – digital twin

The Takitimu North Link project implemented a 3D model-based digital approach (digital twin, or iTwin) to its design and construction that has reduced carbon emissions associated with construction and improved construction efficiency.

The use of the iTwin to design the Takitimu North Link has helped enable earth cuts to be used as fill or deposited onsite. No imported fill is required, and no material is carted offsite. The local road network has been freed of 22,000 truck movements, 900,000km of journeys, which equates to a 560-tonne reduction in carbon emissions.

Case study 13 – CivilShare

CivilShare is an online materials exchange platform for civil contractors in New Zealand. The platform allows contractors to buy, sell, share, swap and hire materials and resources from other contractors in the area, keeping materials and products out of landfill and in use. Users can also exchange ideas and information to help create a more knowledgeable work force.

Case study 14 – Smartcrusher – sand, gravel and cement recovery from concrete

SmartCrusher, from Smart Circular Products in the Netherlands, is a technology for recovering sand, gravel and cement from concrete. The SmartCrusher can decompose concrete rubble into its constituent parts and the cement fraction can also be removed. The recovered sand and gravel can be reused immediately. The cement is separated into hydrated and unhydrated fractions, and the hydrated cemented can be re-used as a filler. The recovered unhydrated cement can serve as a CO_2-free raw material to make new cement and can also be used as a concrete improver. SmartCrusher can also extract steel fibres from reinforced concrete. The steel fibres remain straight and are re-useable immediately.

8. Further information

Further information on circularity or circular economy principles.

- Ellen MacArthur Foundation – Circular economy introduction
- Ellen MacArthur Foundation – Cities and the circular economy
- Circularity Gap Reporting Initiative
- Irish Green Building Council – Towards a circular economy in construction
- The Dutch Circular Construction Economy Transition Team – Circular infrastructure: the road towards a sustainable future

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10. Appendix A: Case studies

Project stage	Resource efficiency theme	Circular economy principle	Case study
Optioneering/ business case	Waste	Designing out waste and pollution	**The High Line, New York** The High Line is a railway line that runs along the west side of Manhattan. The elevated railway was used to transport millions of tons of meat, diary, and produce to the factories in Lower Manhattan. The railway fell into disuse in the late 1990s, and many people were calling it an ugly eyesore with the then mayor of New York signing a demolition order. With strong public advocacy, the transformation into a public park was considered. Today, the High Line is one continuous, 1.45-miles-long greenway featuring more than 500 species of plants and trees. This is an example of build less, as the avoided demolition has ensured resource efficiency through re-purposing a structure, rather than using completely new materials, and sending old materials to waste
Optioneering/ business case	Materials, carbon and waste	Designing out waste and pollution Cycle materials and assets Regenerate natural systems	**SuperBlocks, Barcelona** Historically, cars were the focus while designing the city of Barcelona. Approximately 60% of the public space is for cars and more than one million cars cross the city every day. Superblocks is a strategic plan for the whole city that will turn one out of three streets in the city into green streets by 2030. These are traffic-calmed streets, with priority for pedestrians, and sustainable transport such as trains, subways, trams or bikes, more greenery, and spaces for interaction, play and recreation. A superblock is an area of urban land bounded by arterial roads; within the superblock, the local road network, if any, is designed to serve local needs only, the streets inside serving as public squares for the neighbourhood, widespread pedestrianisation and comprehensive traffic calming. By 2024, the goal is that 80% of trips in Barcelona will be on foot, by bike or by public transport. Superblocks reduce pollution (in Sant Antoni atmospheric pollutants such as NO_2 have dropped by 25%), reduce noise (in Glòries has dropped by 9 decibels), increase sales of local businesses and reduce the number of cars in the superblock area, as well as in the adjacent streets.
Optioneering/ business case	Materials, carbon and waste	Designing out waste and pollution	**Intelligent Traffic Management** Mayflower has partnered with AAEON Technology to help local governments and traffic management groups make road infrastructure improvement decisions. With its lightweight, easy-to-adopt optical sensor, the Mayflower Smart Control Insite Sentinel sensor can be mounted anywhere and moved as needed. The sensors can collect real-time data to help understand traffic patterns, such as classifying vehicles, measuring traffic flow and bicycle lane usage, counting pedestrians, and tracking bike and/ or pedestrian movement. The data is collected and integrated into a digital platform, which can be interrogated and

Project stage	Resource efficiency theme	Circular economy principle	Case study
			analysed to help with early decision making around road infrastructure investments such as the addition or changes to traffic lanes.
Optioneering/ business case	Materials, carbon and waste	Designing out waste and pollution Cycle materials and assets	**Zero-Carbon London Bridge** In this article, Buro Happold explores options for a zero-carbon London Bridge, including reusing the piers, thus making the bridge spans the same as the existing, and also using low-carbon materials such as timber. Current trends show an increase in cyclists, and reduction of motor vehicles, using the bridge. While a new carbon-zero London Bridge will need to meet the requirements for today, this may not always be the case in the future. A primary structure from steel could be built to meet the 120-years design life for a bridge. It could be designed with a width appropriate to the lower expected usage rates for 50 years' time. Timber extensions could be installed to provide extra width and space for the next 30 years, meeting today's demands, and reducing the overall carbon footprint. This is an example of doing less through reducing the amount of steel (by adopting timber materials where possible) and the carbon footprint, as well as creating a more appropriate and adaptable space for future use.
Design	Materials and carbon	Designing out waste and pollution	**A Century Without Maintenance, Geelong's Everlasting Bridge** In 2017, the City of Greater Geelong applied the procurement for innovation concept to a 100-year maintenance-free bridge tender. The tender invited companies to develop solutions to the costly maintenance problem associated with traditional bridges, which cost the city roughly $500,000 to inspect, repair, maintain and replace each year. The winning tender was for a design using a new and innovative combination of materials, which includes geopolymer, made with partly recycled materials, reinforced with carbon fibre that should ensure the bridge requires no maintenance over its 100-year lifespan. The bridge also uses concrete manufactured using fly ash as an alternative to cement. The fly ash concrete reduces corrosion due to its high alkaline composition and utilises a waste product.
Design	Materials, carbon	Designing out waste and pollution	**Thames Tideway Tunnel** The Thames Tideway Tunnel is currently under construction; when completed it will be able to capture and store raw sewage and rainwater discharge, which is currently being discharged out to the river directly. The tunnel showcased circular design principles by reducing the amount of carbon through innovative design and using waste materials in construction. In the east section of the tunnel multiple carbon saving opportunities have been identified within the design of the shaft secondary lining and base slabs. The shaft base slabs sit at the bottom of the giant shafts that will connect the old Victorian

Project stage	Resource efficiency theme	Circular economy principle	Case study
			sewers to the new tunnels. The redesign from a flat structure to a dome-shaped base used 1500 cubic metres of concrete in comparison to 3500 cubic meters for the flat structure, resulting in saving of 750 tonnes of CO_2. The lining through the central section of the tunnel was reviewed, identifying an opportunity to reduce the lining thickness leading to a 16% saving on the volume of concrete used across 12.6km of tunnel, achieving 5% saving on the tunnel's embodied carbon.
Design	Materials, carbon, waste	Designing out waste and pollution	**Resource Efficient House** The Resource Efficient House was designed for Zero Waste Scotland to showcase how the ideas of designing out waste can be successfully incorporated in a building. The building used off-site modular pod construction that allowed for highly adaptable spaces, the building itself could be deconstructed and re-used on another site, and only requires standardised building products without the need for adaptation or off-cuts. The construction of an average three bedroom home akin to the Resource Efficient House can produce up to 13 tonnes of construction waste. With careful designs, the Resource Efficient House produces less than 4 tonnes of construction waste.
Design	Materials	Designing out waste and pollution	**Smart circular bridges** 'Smart circular bridges' (SCB) are made of bio-composites – a combination of organic materials such as flax, and hemp, combined with a bio-resin. The bio-composite materials in the SCBs have about half the strength of aluminium, but the combination of this strength with its lightweight properties give bio-composites great potential for application in building and civil structures. As well as new materials, these SCBs have a new approach to structural safety, by using a self-sensing system. This Structural Health Monitoring (SHM) system constantly monitors the structure and its material behaviour, but it also evaluates its level of structural safety using innovative and sensitive fibre optic sensors (FBGs). Real-time data is constantly collected and evaluated, giving early warnings in case pre-set material limits should be reached.
Design	Waste	Designing out waste and pollution	**Crossrail – designing out waste** The Crossrail project, also known as the Elizabeth line, is a new underground railway line from east to west through central London, providing faster journeys. The line is expected to carry 200 million people a year and raising the rail capacity in London by 10%. Crossrail has followed the Waste Resources Action Programme (WRAP) to support resource efficiency through design out waste workshops. In the workshops, carried out early in the design process with members of the design team, opportunities to

Project stage	Resource efficiency theme	Circular economy principle	Case study
			design out waste and influence the railway and station designs were identified. The opportunities were scored based on their ease on implementation and potential impact to the project.
Design	Materials, waste	Cycle materials and assets	**Crossrail – recycling materials** Crossrail used the Waste Resources Action Programme (WRAP) Net Waste Tool to identify the best opportunities to increase the recycled content of materials used for construction. The Net Waste Tool was developed by WRAP to enable projects to enter cost and quantity data from the project and use its internal database to identify the building components which: • contribute the highest recycled content, and • provide the best opportunities to increase recycled content (known as 'quick wins'). Through this process, Crossrail has been able to achieve an overall recycled content of 36%.
Design	Water	Cycle materials and assets	**Crossrail – best practice in water use** Crossrail required its tier 1 contractors to implement best practice for recycling as much water collected on site as practicable, for reuse during construction and to minimise water use in site accommodation. Several examples of best practices and innovation were employed by Crossrail contractors to achieve water use savings, water use efficiency and water footprinting during the construction of the central section, including using: • groundwater or tunnel ingress water instead of potable (drinkable) water (for activities such as bentonite mixing, slurry dilution, grout mixing, cleaning and dust suppression) • closed loop or semi closed loop drainage systems where water used (including via rainwater and runoff harvesting) • water efficiency measures in Office and Welfare Accommodation • water footprinting and smart metering of water use for specific construction activities.
Design	Materials, waste	Cycle materials and assets	**High Speed 2 (HS2), Birmingham, Manchester, London, UK** The UK's High Speed 2 is a high-speed rail connection connecting Britain's largest economic hubs, Birmingham, Manchester and London. HS2 comprises of large numbers of tunnelling projects. To ensure material circularity, there needed to be an accurate understanding of the material types to enable re-use of the materials in earthworks. This had been especially important in areas underneath central London, due to the tunnelling producing high volumes of London clay spoil. Traditionally, these excavated materials are often transported long distances to be disposed at landfill sites.

Project stage	Resource efficiency theme	Circular economy principle	Case study
			HS2 have done a feasibility study based on circular economy principles to investigate material re-use of the tunnelling spoil. This study looked at using the excavated clay spoils into calcined clay for use as a supplementary cementitious material in concrete and expanded clay for use as lightweight aggregate.
Design	Materials, waste	Cycle materials at their highest value	**Park 20/20** Park 20/20 is a 28-acre business park in the Netherlands built on cradle-to-cradle design principles (a key component of the circular economy). Construction materials are leased from suppliers who retain ownership and can recover and reuse materials when buildings are disassembled. In this way, Park 20/20 acts as a materials bank: the materials are 'withdrawn' at the end of life and reused again at high quality. Energy is produced from solar panels, water is recycled, and waste is converted to biogas to provide an alternate source of energy. Nestled among the buildings are also greenhouses and vegetable gardens used to grow organic fruit and vegetables, which are served in the on-site cafe.
Design	Materials, waste	Cycle materials at their highest value	**Yorkon** Yorkon is a modular building manufacturer that enables the different components and materials to be recovered and reused, rather than being sent to landfill. Yorkon is an off-site manufacturer that pieces together final buildings in situ. This saves money and time as there is less disruption than on-site builds. This method also minimises noise and air pollution due to the speed of installation (new construction techniques, such as 3D printing and off-site prefabrication, can reduce construction time by 50–70%). An existing example is PLACE/Ladywell, the UK's first 'pop-up village' in Lewisham, London. The development, completed in 2016, provides temporary housing (includes 24 x 2-bedroom flats over three levels) and a ground floor community space. The units are modular and can be redeployed in other locations across the borough.
Design	Materials, waste	Cycle materials at their highest value	**Waka Kotahi scour protection emergency works** Waka Kotahi required additional scour protection to prevent riverbed scour further undermining a large rock embankment at a highway site with no nearby detours. Several structural alternatives were available for the emergency works project. The selected option was a wire-rope groyne composed of steel posts embedded within the riverbed and laced together with wire ropes. Initial sources of new materials for the steel posts were newly manufacturing in Australia with shipped to New

Project stage	Resource efficiency theme	Circular economy principle	Case study
			Zealand. An alternative was found by repurposing end-of-life railway track already available in the country. This approach reduced cost, avoided shipping delays, and adopts circularity principles through using non-virgin materials, while providing a similar level of performance to a new product.
Design	Carbon	Designing out waste and pollution	**Solar highway – Shandong, China** In 2017 China opened a 1km solar highway, which contains solar powered batteries beneath transparent concrete. The highway spans 5875 square meters and it is capable of generating enough electricity to power 800 homes a year. The project will save space for constructing solar farms and shorten the distance of transmission. If two lanes of every expressway in China are retrofitted as solar highways, there could be 7 million GWh of power every year, the equivalent of almost 1.3 times the total residential energy consumption in China, and could cut greenhouse gases emissions by 7.2 billion tonnes.
Design	Water	Regenerate natural systems	**Te Auaunga Restoration, Auckland** Te Auaunga Restoration is a healthy waters project by Auckland Council involving extensive modifications and upgrades for Te Auaunga Awa (Oakley Creek) Auckland. These upgrades saw the transformation of the 1.5km-long waterway from a concrete-lined, fast-flowing culvert to a naturalised, meandering stream replete with native planting. The project has daylighted seven piped tributaries, restored eight hectares of open space, and treated the water quality of the contributing catchment. A central focus of this upgrade was stormwater and flooding management, as surrounding properties were known to flood following large rain events. Significant social and cultural dimensions to the design of the upgrade emerged through engagement with mana whenua, the establishment of a community advisory group and several innovative social procurement processes.
Design	Water	Regenerate natural systems	**Awaruku Stream Remediation, Auckland** Adjacent to the Awaruku wetland in Torbay on the Hauraki Gulf is the Awaruku Stream, which discharges directly into Long Bay-Okura Marine Reserve. The stream is subject to ongoing erosion due to hydrological changes in the area and the removal of sediment bed load from the wetland. The Awaruku Stream Remediation project involved a 'soft-engineering approach' to remediate the erosion through planting native vegetation, reducing the level of the stream banks and installing riffle structures. When native lizards and fish were discovered onsite, the designed solution considered the habitat needs of those species. In addition to riffle structures, stabilised undercuts were formed for fish to use as a refuge. Rock piles were built as a natural retreat for lizards.

Project stage	Resource efficiency theme	Circular economy principle	Case study
Design	Water	Regenerate natural systems	**Hairini wetland restoration, Tauranga** For the construction of the Maungatapu underpass, part of the Hairini Link project, around 7,700 square metres of wetland had to be removed, with plans to restore two nearby wetlands: Te Pahou and Tongaparaoa. In 2019, Waka Kotahi teamed up with Te Rōpū Aonui Hou, a collective of three hapū: Ngāi Te Ahi, Ngāti Hē and Ngāti Ruahine, for the restoration project. By the end of 2022, more than 60,000 native plants will have been planted, most sourced from a local native plant nursery, which was initially established to preserve the whakapapa of local species and to create employment opportunities on the backend of the downturn in the forestry mill industry in the area.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**The first circular viaduct in the Netherlands** In practice, viaducts in the Netherlands hardly reach their technical lifespan and are demolished much earlier for functional reasons. This led to the project leader at van Hattum en Blankevoort (vHeB), challenging the team before getting started with the construction of a new viaduct: Why not make it circular? The prototype is a 20m-long bridge which is modular, scalable, de/re-mountable, and therefore fully re-usable solution. More specifically, a demountable bridge deck, working with prestressing without attachment and 'shear keys'. On 4 December 2018, five girders arrived at the Kampen site. Thirty-two bars were fixed though the girders. The main contractor was the first to successfully cross the viaduct in his car, followed by a large convoy of trucks and road vehicles. At the beginning of September 2019, the circular viaduct was dismantled successfully and without damage in its original five girders. After being transported to a temporary storage facility at Consolis Spanbeton, one of those was also disassembled into the eight concrete elements that form a girder for further examination. With this step successfully completed, the viaduct awaits a new destination where it will be re-assembled.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**Bailey bridges** A Baily bridge is used to provide temporary connection while a damaged bridge is repaired or rebuilt. The structure is a prefabricated single-lane bridge that can be installed relatively quickly. Bailey bridges have been used around the world for the past 80 years with some of the most common uses in New Zealand have been: • replacing collapsed bridges • restoring access to roads washed out in storms • providing a cost-effective temporary structure for roading projects • providing minor stream crossing for movie locations and other non-emergency situations.

Project stage	Resource efficiency theme	Circular economy principle	Case study
			The basic component of a Bailey bridge is a 3-metre-long truss panel, which can be configured to provide longer spans if necessary. A Bailey bridge is a good example of a temporary structure which can be reused and reassembled several times in various situations.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**Smartcrusher – sand, gravel and cement recovery from concrete** SmartCrusher, from Smart Circular Products in the Netherlands, is a technology for recovering sand, gravel and cement from concrete. The SmartCrusher can decompose concrete rubble into its constituent parts and the cement fraction can also be removed. The recovered sand and gravel can be reused immediately. The cement is separated into hydrated and unhydrated fractions, and the hydrated cemented can be re-used as a filler. The recovered unhydrated cement can serve as a CO2-free raw material to make new cement and can also be used as a concrete improver. SmartCrusher can also extract steel fibres from reinforced concrete. The steel fibres remain straight and are re-useable immediately.
Construction and maintenance	Materials, carbon	Design out waste and pollution	**Takitimu North Link project –digital twin** The Takitimu North Link project implemented a 3D model-based digital approach (digital twin, or iTwin) to its design and construction that has reduced carbon emissions associated with construction and improved construction efficiency. The use of the iTwin to design the Takitimu North Link has helped enable earth cuts to be used as fill or deposited onsite. No imported fill is required, and no material is carted offsite. The local road network has been freed of 22,000 truck movements, 900,000km of journeys, which equates to a 560-tonne reduction in carbon emissions.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**CivilShare** CivilShare is an online materials exchange platform for civil contractors in New Zealand. The platform allows contractors to buy, sell, share, swap and hire materials and resources from other contractors in the area, keeping materials and products out of landfill and in use. Users can also exchange ideas and information to help create a more knowledgeable work force.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**Nationale Bruggenbank, National Bridges Bank, Netherlands** The cities of Amsterdam and Rotterdam have joined forces with Rijkswaterstaat (Netherlands Directorate-General for Public Works and Water Management) and the Bruggenstichting (Dutch Bridge Foundation) to establish an independent platform for reusing bridges and bridge components. The objective is to provide all infrastructure authorities with an accessible means of reusing bridges. The integral reuse of bridges that are still in good condition is fully compatible with the Dutch government's ambition to be climate neutral and to establish a circular economy by 2050**.**

Project stage	Resource efficiency theme	Circular economy principle	Case study
			The digital platform includes a catalogue of bridges currently available, including information on the bridge such as function, materials, dimensions, location, (shown on a map) and the date from when the bridge would be available. The site also includes guidelines for the use of bridges (in Dutch), outlining the steps to take when considering reusing a bridge or offering one for reuse.
Construction and maintenance	Materials, waste	Cycle materials at their highest value	**Green Gorilla** The majority of the waste sent to municipal landfills is construction and demolition (C&D) material. Every year, over 570,000 tonnes of C&D trash are dumped in landfills in Auckland. Green Gorilla, a Kiwi-owned business, is attempting to reduce this sizeable waste stream. They have received more than $5 million in funding from the government's Waste Minimisation Fund to achieve this. In their specialised waste processing plant in Onehunga, which was inaugurated in 2012, Green Gorilla processes roughly 6,000 tonnes of C&D trash each month. About 75% of the C&D materials that Green Gorilla processes are kept out of Auckland landfills by being recycled on-site or given to other businesses to recycle or reuse. Waste timber makes up 20–30% of the C&D waste collected and adds to landfill greenhouse gas emissions. By segregating treated and untreated wood, Green Gorilla diverts both types of wood into products including biofuel, landscaping wood chips, and animal bedding. Steel, paper and gypsum are other materials that Green Gorilla collects and processes.