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Circular Infrastructure: the road towards a sustainable future

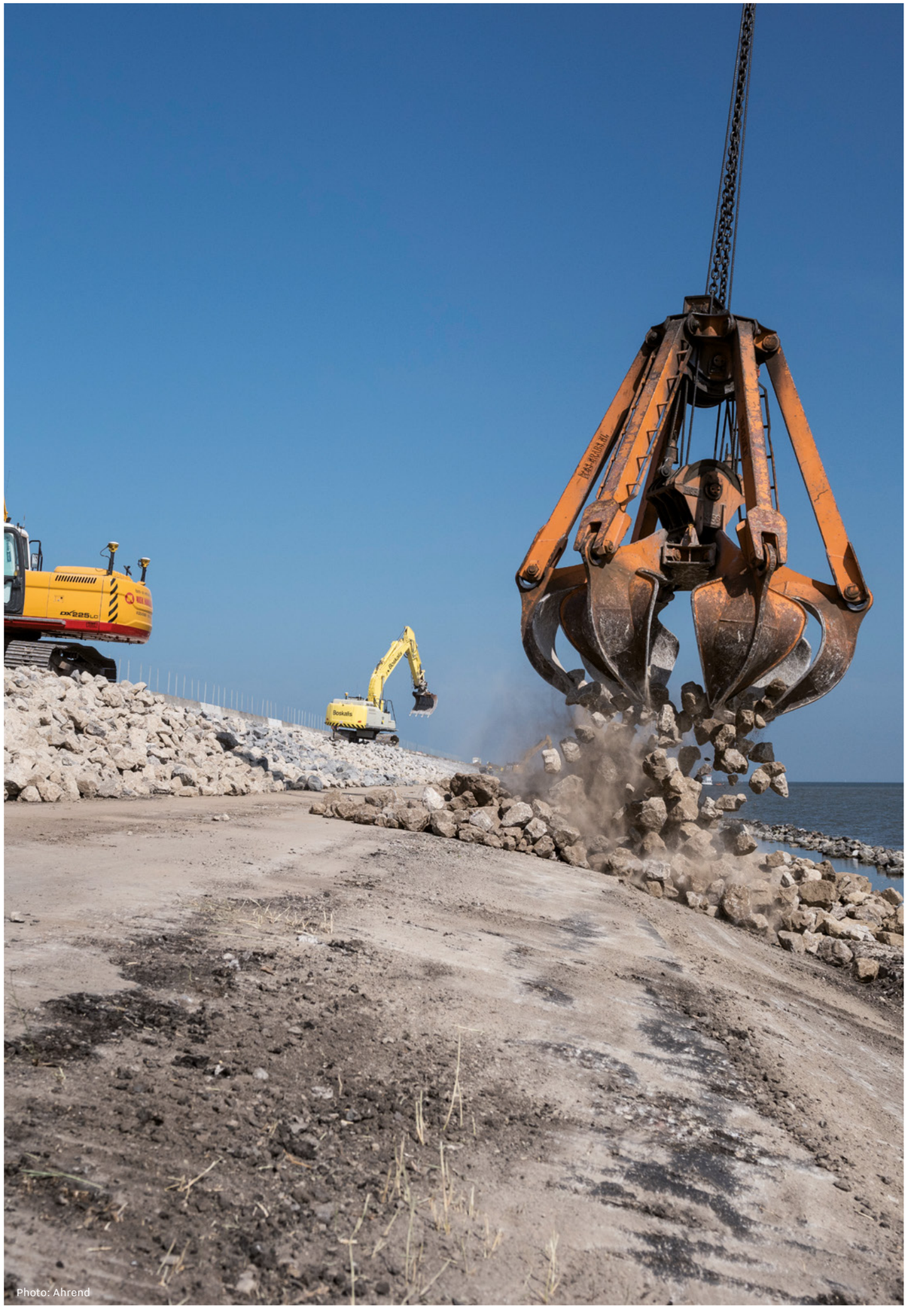

Photo: Ahrend

Content

"Circular infrastructure has clear potential to bring about long-term impact in terms of climate change mitigation and resource scarcity and contribute to therealization of the 1.5°C Paris Agreement target"

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Circular Infrastructure: the road towards a sustainable future

Buildings and infrastructure play an undeniably crucial role in our wellbeing, health and safety.

Infrastructure - such as road, rail and waterways - makes up a significant part of the built environment and is the backbone of a healthy economy. Infrastructure enables trade, powers businesses, connects workers to their jobs, creates opportunities for struggling communities and protects the nation from an increasingly unpredictable natural environment. The economy needs reliable infrastructure to connect supply chains and efficiently move goods and services across borders.

However, construction consumes around 60% of the world's materials and is responsible for around 53% of the world's greenhouse gas emissions, a big part of which is atrributed to infrastructure. Population growth, the need for more infrastructure in developing countries, and climate change will place new challenges and demands on already exhausted/depleted infrastructure and unprece-dented pressure on the availability of raw materials.

In the Netherlands, the Construction sector is one of the key sectors in the transition to a Circular Economy. A dedicated Dutch 'Circular Construction Economy' Transition Team with public, private and knowledge partners has been set up with a clear strategy to achieve a circular construction economy by 2050.

The strategy and goals document geared towards 2023 states that:

"It is very important that the progress made in terms of circular construction in the Netherlands corresponds with developments in the rest of Europe (and vice-versa)."

As the chairman of the transition team, I am therefore very pleased with this publication.

It clearly shows the enormous potential of circular infrastructure, the need for international cooperation and the best practices and knowledge that the Netherlands has to offer as a partner in reaching our joint circular and climate goals. These solutions can inspire the world and create opportunities for frontrunners.

In the global drive towards circular and net zero economies, infrastructure has an essential role to play. Circular infrastructure has clear potential to bring about long-term impact in terms of climate change mitigation and resource scarcity and contribute to the realization of the 1.5ºC Paris Agreement target, as recently re-emphasized during the UN Climate Change Conference.

Now is the time to act. The COVID-19 pandemic has shown first-hand how vulnerable supply chains are worldwide and how shortages of (critical) raw materials can affect the delivery and pricing of infrastructure projects. Strengthening efforts to transition to a circular infrastructure internationally is needed to

secure sustainable supply and diversify material sources. As infrastructural projects tend to be large, create jobs, have a long life span, and are more often than not government-driven, they are ideal projects for post-COVID-19 green recovery funding. International cooperation to change the way green infrastructure projects are financed is of vital importance and comes at a timely moment.

Across the globe government actors are detailing ambitious infrastructure plans. The European Union recently agreed on an infrastructure plan similar to China's new Silk Road, President Biden reached a deal for mega investments in the U.S. infrastructure and the G7 launched the Build Back Better World initiative. Based on these plans announced by government actors, a wave of infrastructure projects - renovations, replacements and new constructions - is expected in the coming years.

In Europe, the EU Green Deal, the new Circular Economy Action Plan and the EU Taxonomy, for instance, can be major policy drivers for circular change in infrastructure.

For a circular infrastructure to reach its full potential and scale necessary for a sustainable future, we need to work together. International cooperation is paramount to boost knowledge and innovation development, to ensure alignment and harmonization of protocols, norms and standards for driving more circularity in infrastructure, to create a well-functioning common market for renewable and secondary raw materials and to make sure that the use of raw materials is increasingly efficient and of high quality.

The good news is: circular solutions already exist across the entire value chain and we can start from existing knowledge and lessons learned about how to make infrastructure circular and climate neutral. Initiatives such as dedicated chain collaboration programmes, circular public procurement, circular data strategies and design principles for infrastructure, circular indicators and measurement methods have proven successful in providing clear insights and guidance to a wide range of stakeholders in order to advance the transition.

By joining forces, the Transition Team for Circular Construction Economy, Rijkswaterstaat, Holland Circular Hotspot and TNO, have bundled their expertise, insights, networks and a number of demonstration cases in this publication. I hope it will inspire you all to take action and kick-start circular infrastructure development in other parts of the world.

The Transition Team for Circular Construction Economy will, together with the sector, further develop the proposal for an International Action Plan in this publication.

For us, Circular Infrastructure is the road towards a sustainable future; join us on this road and do not hesitate to contact the authors for further information.

Introduction and Context

Infrastructure is one of the cornerstones of our global economy. Its availability and quality directly affects a country or region's GDP, employment rates, and its overall livelihood. Networks such as roads, railways, and waterways are public assets that facilitate the movement of billions of people every day and provide them with the products and services they need. The value of infrastructure in our lives is indisputable, but so is its environmental impact.

In a fight against global warming, infrastructure has a tremendous role to play. Currently, the total construction sector consumes around 60% of the world's raw materials and the global share of greenhouse gas (GHG) emissions from the construction value chain is estimated at 53%, much of which is attributed to the heavy materials it consumes.[1] Infrastructure is responsible for a large part of that. In the coming decades, demand for infrastructure is bound to increase as a natural consequence of a growing population and its need for products and services. Additionally, many of the current infrastructural elements are aging and need to be replaced soon, specifically in Europe. The construction sector is responsible for delivering infrastructure, and in the European Union, this sector is responsible for over 35% of total waste generation.[2]

In preparation for a post covid-19 world, investments in infrastructure are being deployed around the world to help recover from the setback. Recovery funds all over Europe are being pumped into infrastructure developments. Similarly, the US Congress has recently passed a 1 trillion USD infrastructure bill, and China is constantly increasing its infrastructure expenditures in order to keep up with the country's economic growth. A similar pattern can be observed in nations across the globe.

Despite the long-term nature of infrastructure life expectancy, it is often that we see these structures demolished before the end of their technical lifespan for functional reasons. This results in unnecessary waste and pollution that can be avoided through better planning, innovative design, and creative business models based on the principles of circular economy. Furthermore, it is estimated that greater material efficiency could save 80% of emissions related to infrastructure[3].

This publication explores how circular economy concepts can help tackle the challenges infrastructure faces, supporting the transition towards a more sustainable and futureproof infrastructure sector. It showcases best practices from the Netherlands, which is a country with challenging terrains and a pioneering infrastructural system upon which its very existence depends. An action agenda is presented in the concluding chapter, calling for international cooperation to unlock the potential of circular infrastructure in the global run towards climate neutrality and circular economy. It proposes an international action agenda which looks in more detail at what is needed to realize the transition to circular infrastructure on both the EU and international levels.

Chapter 1

The infrastructure sector

Construction, buildings, and infrastructure

The construction sector is responsible for establishing buildings and infrastructure which are essential to achieving a functioning society. It is a sector of high strategic importance as it plays a major role in the socio-economic development of countries around the world. The sector also has a major impact on local employment and quality of life within a nation. In the EU, the construction sector employs 18 million people and contributes close to 9% to the EU's GDP[4]. The quality and effectiveness of the construction sector determine the strength of our infrastructure and the vitality of the environment in which we live.

The construction sector is also a major consumer of intermediate products such as water, chemicals, and electronic equipment, as well as related services. It is the world's largest consumer of raw materials[5]. In the EU, it accounts for about a half of all the extracted materials and energy consumed, and about a third of our water consumption, waste generations, and CO2 emissions[6] (figure 1). In the Netherlands, the numbers are in line with the EU, an estimate of 50% of resource consumption, 40% of the total energy consumption, and 30% of the total water consumption. Construction and demolition waste discarded in the Netherlands is responsible for 35% of all CO2-emissions[7].

The construction sector is generally subdivided into buildings (residential and non residential) and infrastructure works. These are different market segments, each with its own dynamics, stakeholders, and rules. As a result, each requires a custom approach. Despite their differences, both segments are highly interdependent and share many similarities.

Figure 1: Impact of the construction sector

Source: European Commission. 2021. Level(s), What's in it for construction companies and contractors, manufacturers, asset managers, facilities managers, and occupants?. [online] Available at: https://op.europa.eu/en/publication-detail/-/publication/49f1bd5f-143e-11ec-b4fe-01aa75ed71a1/language-en/format-PDF/source-search [Accessed 16 November 2021].

What is infrastructure?

Infrastructure, also known as “civil engineering works” or “public works”, is the basic physical system of a region or country. Examples of infrastructure include transportation systems, waterways, communication networks, and electrical systems. These systems are typically capital- and cost-intensive and require significant investments. They are vital to a country's economic prosperity.

Examples of infrastructure works:

- **Dredging, coastal, and riverbank projects:** consists of the traditional dredging (for both new constructions and maintenance projects), the construction of dams, dykes, and such activities raising industrial estates and integral coastal and land reclamation;
- **Concrete and waterway construction:** this concerns the construction of civil objects for dry and wet infrastructure (tunnels, viaducts, aqueducts, bridges, port installations, etc.). Particularly when it comes to wet infrastructure, Dutch constructors have a strong (international) reputation;
- **Road construction:** the construction of new roads and the maintenance of existing roads. Traditionally, groundwork and the construction of sewer pipes are linked to road construction. Businesses cooperate extensively in this sector and trade associations have a strong position;
- **Cables, ducts, and pipes:** in this sub-sector, a lot of work is done for utility companies. In terms of its structure, this sub-sector has the most in common with the residential and nonresidential construction sector. Small, regionally operating family businesses are particularly prevalent in the cable sector. Among pipe constructors, a number of bigger organizations – most with ties to major conglomerates – are active;
- **Environmental construction:** soil sanitation, water purification, cleaning up water beds, processing chemical waste, etc.
- **Railways:** railway infrastructure concerns all the structures, buildings, land work and equipment that support trains and rail lines.

Source: Rijkswaterstaat

Materials in infrastructure

The construction sector is one of the largest consumers of (heavy) raw materials. It consumes around 63% of all materials in the world[8], and infrastructure is responsible for a large part of that. In the Netherlands, more than 20 million tons of materials are used to expand and improve roads, canals, and underground infrastructure every year[9]. Examples of materials used in infrastructure works are asphalt, concrete, cement, plastics, clay, sand, and steel. In the Netherlands, supply-chain initiatives are also working on the development of timber as a more sustainable building material for infrastructure works.

Concrete is the most widely used man-made material in existence and second only to water as the most-consumed resource on the planet[10]. This popularity is due to the inherent properties of concrete that make it a perfect material when it comes to building structures. Flexibility in shaping, durability, high resistance to compression, fire and water. It does however come with some drawbacks. **Cement**, which is the main binding material in concrete, is on its own responsible for around 8% of the world’s CO2 emissions[11]. It is also extremely water and energy-intensive during its production phase.

Steel is another fundamentally relied-upon material in infrastructure due to its durability, flexibility, stress resistance, and its high density that allows the realization of relatively lightweight structures. It is used in almost all structural elements and transport networks. The construction of infrastructure and buildings is estimated to account for more than 50% of the world’s steel demand[12]. Similar to cement, steel production is a major contributor to climate change. According to the world steel association, every ton of steel produced in 2018 emitted on average 1.85 tons of carbon dioxide, equating to about 8% of global CO2 emissions[13]. On the other hand, steel is a 100% recyclable material and keeps almost all of its original properties when reused.

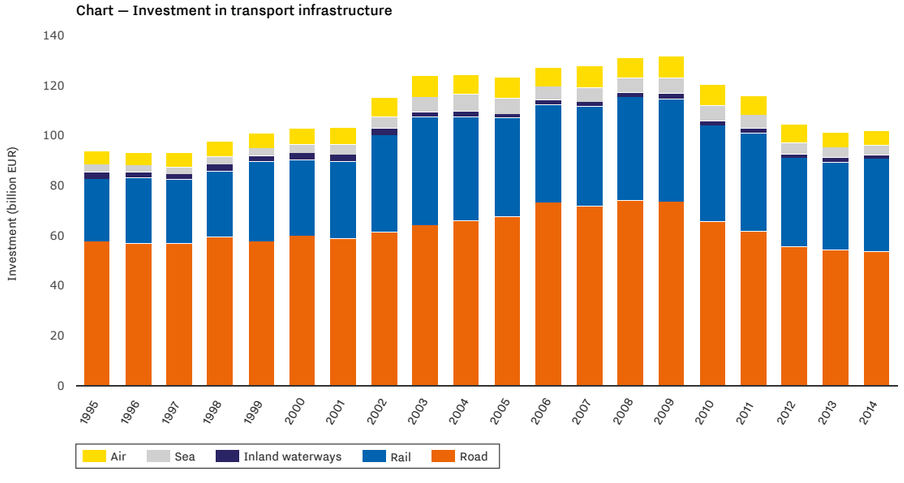
Asphalt is a mixture of mineral aggregates, bitumen binder, and filler, used for paving roads, parking areas, railway tracks, ports, airport runways, bicycle lanes, sidewalks, and sports areas[14]. Aggregates used for asphalt mixtures can be from crushed rock, sand, gravel, or slags. Secondary materials in the form of construction and demolition debris are often used as a filling layer applied underneath asphalt. The main binding material in asphalt is traditionally bitumen, which is a non-renewable petrol-based substance that is increasingly difficult to find and is of inferior quality.

EU investments in transport infrastructure:

Investments in transport infrastructure among the EU member states have been steadily increasing since the 1990s, peaking in 2009 (figure 2). The majority of the expenditures goes to road infrastructure, which accounted for 52% of the total spending in 2014.

An important trend to note is the consistent increase in investments allocated to rail infrastructure. From 27% in 1995, to 30% in 2000, up to 37% in 2014. This is in line of the EU’s objective of shifting traffic to more environmentally friendly modes[15].

Figure 2: EU investments in transport infrastructure (1995-2014)



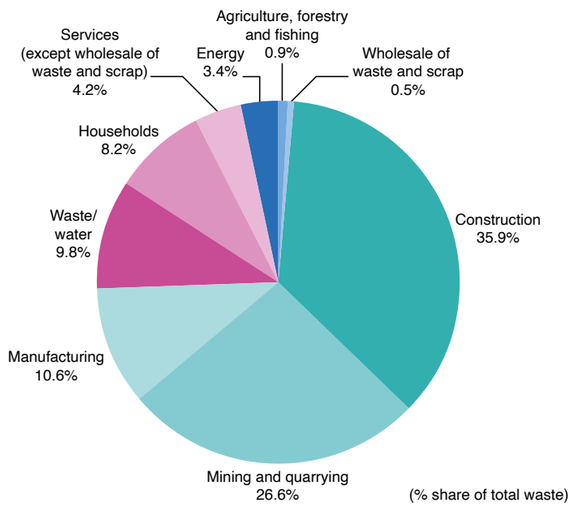
Source: https://www.eea.europa.eu/data-and-maps/indicators/infrastructure-investments/assessment-3

Infrastructure specific features

Infrastructure has a number of specific features that require dedicated approaches to realize. Infrastructure works are often not very complex from a technical perspective, yet they do have a very long lifespan (50-100 years)[16]. The sector is highly government-dominated and consolidated, thus it deals with public tenders in the form of long-term investments and a small number of (homogenous) stakeholders. Infrastructure is known for its very long planning processes, which makes it less innovative compared to other sectors and lagging behind in terms of developments. In the global run-up to sustainable development, more flexibility is needed in infrastructure planning processes to incorporate new and sustainable approaches and technologies in the implementation of projects. The incorporation of such innovations should not be hindered by choices that were made many years before.

In the field of infrastructure, safety and availability are of major importance. Projects focus strongly on completion within scope, budget, and time, which often results in risk aversion. That is why it is essential to think about creating room for innovations and experiments in projects, risk-sharing, and also including sustainability in the scope of projects. Moreover, due to rapid developments in the field of smart mobility, infrastructure faces relatively high uncertainty in predicting future mobility needs since it is highly dependent on the future of vehicles. There are major question marks about what roads and other civil engineering works should look like in the future and whether or not we will actually still need roads. Nonetheless, we can say that infrastructure in itself will never become obsolete and the only thing that will change is the desired scope or capacity contrary to the design[17].

Figure 3: Waste generation by economic activities and households, EU, 2018



Source: eurostat. 2021. Waste statistics. [online] Ec.europa.eu. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#Total_waste_generation [Accessed 24 November 2021].

Challenges facing the Infrastructure Sector

The world is changing around us every day. Macrotrends, such as population growth, migration rates to cities, increased demand for products and services, as well as climate change and the loss of biodiversity, are all factors that are putting pressure on all economic sectors to future-proof their processes and activities. Infrastructure included.

Climate change and waste

Infrastructure requires vast amounts of resources and is expected to consume more than half of the world's projected materials by 2060. It contributes about 10% of global GHG emissions through the construction phase alone and 43% during operations[18]. Most of the emissions come from the production of materials for road constructions, bridges, viaducts, and from the transport of raw materials[19]. Adopting circular economy principles across the infrastructure value chain has the potential to address up to 19% of total infrastructure emissions.

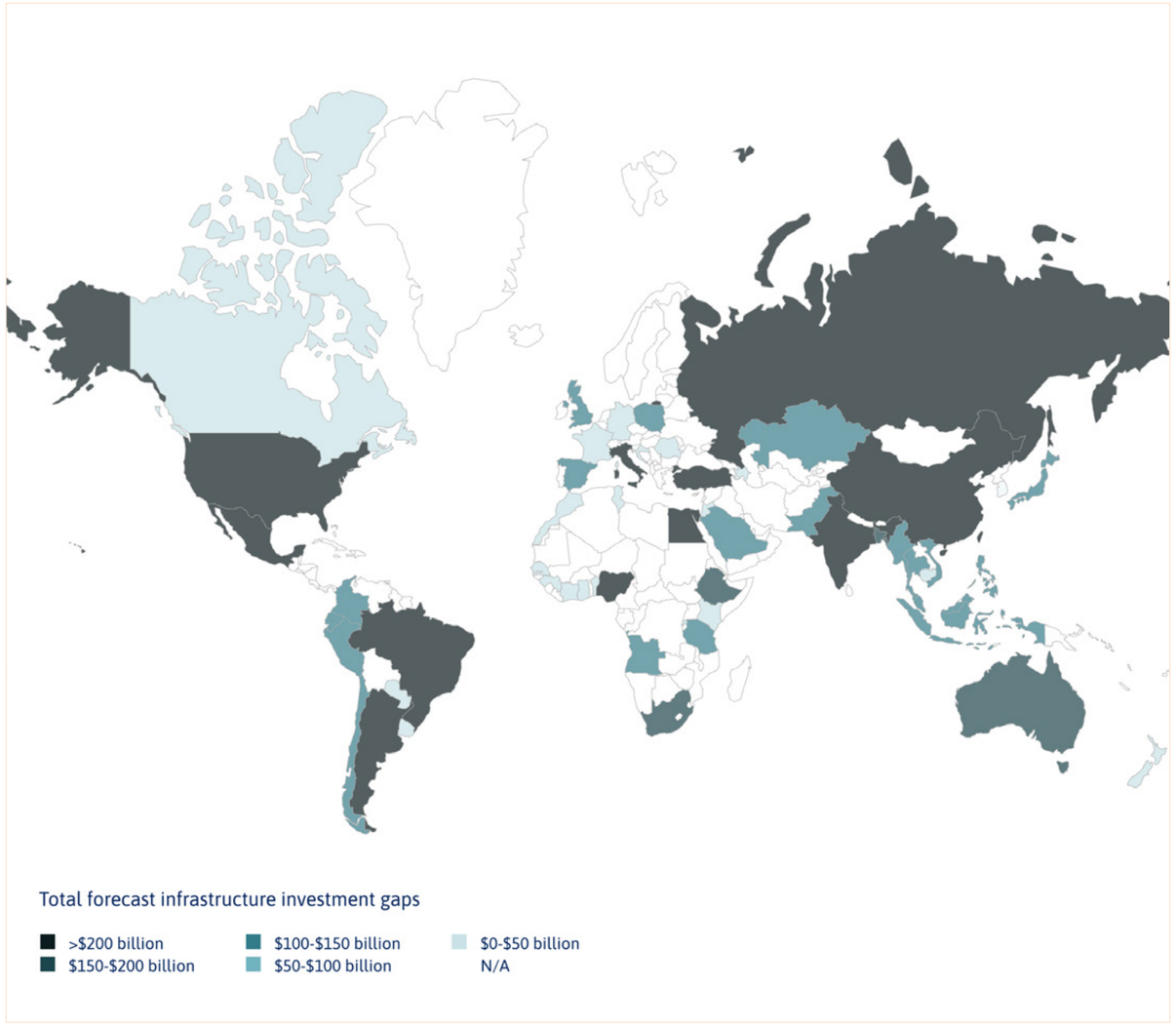
In the Netherlands, half of all materials used in the construction sector are used in infrastructure. This includes groundworks and materials such as concrete, steel, and asphalt. These materials contribute significantly to climate change, with emissions of approximately: 2800 kton CO2-eq[20], of which the national infrastructure contributes 612 kton and rail infrastructure 115 kton CO2-eq.

A significant amount of the overall waste generated globally is construction and demolition (C&D) waste, which also includes C&D waste from infrastructure. In Europe, C&D and the mining and quarrying activities amounted to 62.5% of the overall waste generated in 2018 (see figure 3). In The Netherlands approximately 97% of C&D from buildings is reused in infrastructure, this is however mostly lower value downcycling to granulate for road foundation[21].

Resource depletion

Despite their environmental impact, raw materials are critical to the infrastructure sector and in general for global economy. Ensuring a reliable and unhindered supply of raw materials is a long-standing issue, especially during the crisis we are living in. The COVID-19 pandemic has disrupted supply chains worldwide and revealed vulnerabilities on a scale never before experienced. Shortages of (critical) raw materials (and consequently rising prices) and transportation bottlenecks have slowed down infrastructure projects, clearly demonstrating the fragility of our supply systems and resource depletion[22]. It is therefore paramount to diversify sources of primary raw materials, strengthen domestic sourcing, and support the supply of secondary raw materials through resource efficiency and circularity. In addition to this, international cooperation is also of great importance.

Figure 4: Global infrastructure investment gaps



Source: Global Infrastructure Hub. 2021a. Global Infrastructure Outlook - A G20 INITIATIVE. [online] Available at: https://outlook.gihub.org/

Increasing demand for materials

There is a strong directly proportional correlation within the G20 countries between the demand for materials and resources and the size of the population and the economy in terms of GDP. With a global population set to grow by 20% to almost 10 billion by 2050[23], demand for materials is bound to increase as well. An estimated 60% equivalent of the existing infrastructure is needed to cope with this increase. This is similar to building a new Paris every week for the next 30 years. This highlights the strain and scarcity of materials that could consequently be experienced following the current trajectory of consumption[24].

Demand for infrastructure expansions and replacements extends to developing countries as well. According to the Infrastructure Outlook, the investment needed in infrastructure in the 56 studied countries (figure 4) worldwide will double by 2040 compared to investments in 2015, from 2.3 to USD 4.6 trillion[25]. The value delivered by the infrastructure, if not decoupled from the raw, nonrenewable, and energy/carbon-intensive materials used in the process, will lead to catastrophic climate disruption.

Aging infrastructure

On several fronts and in many different European countries, much of the key infrastructure is becoming obsolete. European countries have relied upon post-war infrastructure and facilities dating back to the 1950s and 1960s. Europe's aging infrastructure made international headlines in August 2018 when a highway bridge in Genoa, Italy collapsed, killing 43 people[26]. The tragedy

shed light on the poor maintenance of aging infrastructure across Europe, a problem that has long concerned operators in the sector.

In the Netherlands, infrastructure is facing the biggest maintenance operation ever. In the coming years, more than 130 national bridges, tunnels, locks, and viaducts have to be replaced or renovated[27]. It concerns 40 projects, with an expected budget of around EUR 1.5 billion. Appropriate maintenance, renovation, and repair of these public works through design, innovation, and research can contribute to making the sector sustainable and future-proof. Given the labor-intensive nature of the sector, infrastructure renovations can also play a crucial role in European economic recovery after the COVID-19 pandemic.

In general, maintaining existing - and building new - infrastructure requires significant investments, let alone making it future-proof. This can lead to a major financial challenge if not tackled in a timely and sustainable manner.

Opportunities

We have seen that infrastructure has a high environmental impact from material use, waste production, and CO2 emissions. The sector, therefore, offers enormous opportunities to tackle climate change through high-quality reuse and recycling, circular design, and the use of renewable materials. According to TNO, the CO2 emissions from infrastructure can be reduced by as much as 40% through more efficient use of energy and materials, extending the lifespan, more re-use, and innovative materials, products, and processes[28]. The following chapters will further explore how Circular Economy concepts can play a role in future-proofing the infrastructure sector and limiting its environmental impact, following the sustainable development goals and contributing to the prosperity of our planet and all its inhabitants.

Chapter 2

Circular economy & infrastructure

Infrastructure faces a number of major social and environmental challenges. As previously discussed, due to the growing population and increasing living standards, the sector is expected to grow worldwide in the coming years. But the construction of new infrastructure, as well as maintenance and renovation of existing infrastructural systems comes with a heavy toll on the environment. In this chapter, we introduce the concept of Circular Economy and illustrate how the application of circular concepts can contribute to building a healthier, less harmful, and generally more sustainable infrastructure system.

What is a circular economy?

Circular economy is an economic model that favors the preservation of natural resources and decoupling of economic growth from material consumption over the entire lifecycle of products and services. It contradicts the linear (take, make, dispose) economic system that is still widely adopted across industries.

The key to a circular economy is closing the loop of products and raw materials, keeping them in use as intensively and as long as possible, preventing wastage and waste as much as possible (along the Ladder of Circularity (10-R)). When discarded, products and materials are reused and recycled. Where new materials are added, they have a low environmental footprint, e.g. natural, renewable and regenerative materials used instead of fossil based primary materials.

It's about much more than waste management ..

The term circular economy is often and mistakenly used interchangeably with terms such as "recycling" or "waste management". As much as end-of-life processes play a fundamental role in the transition to a circular economy this misconception is far from accurate. Circular economy is about value retention along the whole supply chain and life cycle of a product or service and designing out waste and emissions from the beginning.

The circular strategies in figure 5 represent 4 main goals when it comes to material loops:

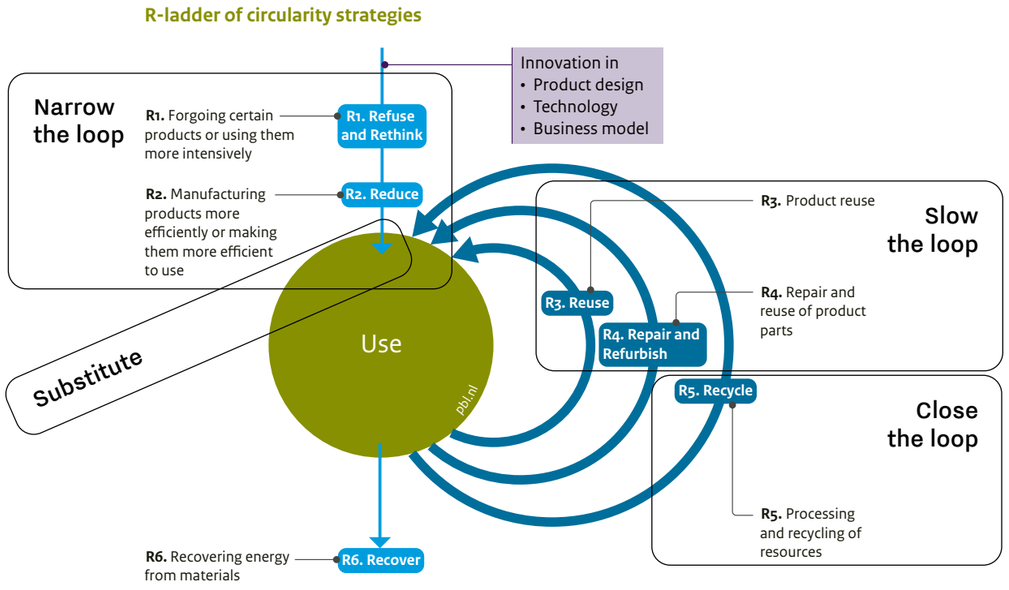
1. **Narrowing resource loops (reducing the input of resources) by refusing the use of products (prevention) when possible, intensifying the use of products or reducing the use of materials through more efficient manufacturing or efficiency in using them;**

2. **Slowing down or elongating resource loops (longer and high value use of materials and products) by reuse, repair, and remanufacturing of products;**

3. **Closing the loops (reducing loss of materials through waste) by recycling and recovering energy from materials when all the previous options are no longer possible.**

4. **Substitution where applicable. This includes the use of biobased, renewable materials instead of primary abiotic materials.**

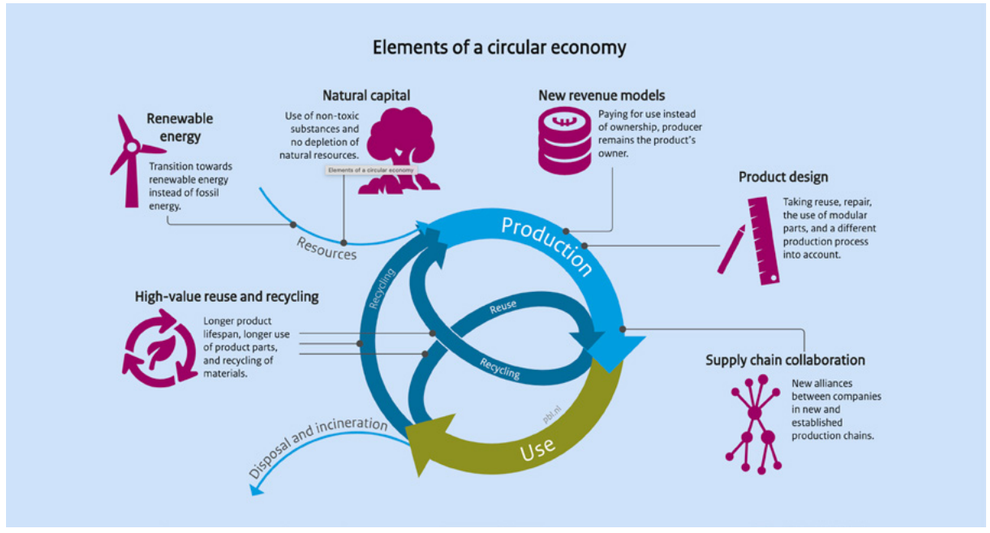
Figure 5: R ladder and circular economy strategies: more than recycling



Source: Potting, J. and Hanemaaijer, A., 2018. Circular economy: what we want to know and can measure. [online] PBL Netherlands Environmental Assessment Agency. Available at: https://www.pbl.nl/sites/default/files/downloads/pbl-2018-circular-economy-what-we-want-to-know-and-can-measure-3217.pdf [Accessed 26 December 2021] - Edited by the Ministry of Infrastructure and Water Management

Circular Economy principles (figure 6) offer a holistic and realistic approach to facing the world's most pressing challenge: accommodating for a growing population's demand for products and services without exceeding earth's capacity and depleting its natural resources, all while keeping global temperature rise within the 1.5 C boundary and without sacrificing the economic return from business practices. The circular economy approach makes this possible through innovative design principles and business models, value-chain collaborations and procurement schemes, making use of digital technologies and technical innovations, aiming at a complete system change.

Figure 6: Elements of a circular economy



Source: Rood, T., Hanemaaijer, A. and PBL Netherlands Environmental Assessment Agency. 2017. Opportunities for a circular economy. [online] Available at: https://themasites.pbl.nl/o/circular-economy/ [Accessed 17 November 2021].

A circular infrastructure economy

Circular economy principles can help solve infrastructure sector challenges in several ways. Circular design pre-integrates lifespan considerations, and future reuse of materials and structures at every stage of the project. Asset management is another very important aspect. By developing circular maintenance and renovation strategies, asset managers can make choices to ensure that materials and structures from a built asset remain in use for as long as possible.

At the end of an asset's lifespan, high-quality recycling and reuse of materials can address the huge amounts of construction and demolition waste, resource scarcity, and environmental impact associated with material production. The increasing need to phase out the use of (scarce) primary resources can also drive the sector towards the use of renewable and bio-based materials, such as timber, hemp, and elephant grass. However, many new solutions and innovations still need to be developed for high-quality recycling and reuse of materials, sustainable production, and service-life extension of materials.

To achieve high-quality reuse, it is required to have insights into the quantity and quality of the materials and structures of a built asset and their availability for reuse. With this information, it becomes clear when parts of an old bridge for instance can be reused for a new bridge. Digital technologies such as material passports or digital logbooks can track the journeys of products, components, and materials. Circular data strategies need to be developed to make the resulting data securely accessible over the full lifespan of the construction. Digital solutions and sustainable business models and services (e.g. products-as-service) will not only dematerialize our economies and make them less dependent on primary resources, but also create innovative jobs and upgrade knowledge and skills. In addition to data, developing methods to measure circularity is essential to make informed decisions. For instance, in the design phase and procurement, and to monitor progress.

Infrastructure works are often procured by the public sector. The huge procurement volumes of public works offer unique opportunities to lead the way towards an interesting market for stakeholders to develop climate-neutral and circular solutions. Moreover, because the commission of infrastructure projects is highly centralized, fewer parties need to be involved in the process and steps may be carried out more quickly. Circular procurement can therefore offer additional opportunities to transition to circularity. Nevertheless, structural attention to public procurement and long-term policies are needed for the market to invest in circular innovations.

An integrated approach to maximise benefits

Although infrastructure has specific features, infrastructure works and buildings share many similarities like digital logbooks, circular design, measurement methods, and more. They are also highly interdependent in terms of material flows, supply chains, standards and norms. Take material flows for instance: a very high percentage of the construction and demolition waste from buildings is reused in the infra. Although aggregates offer additional benefits compared to traditional foundations, construction and demolition waste from buildings will increasingly flow back to new buildings in a circular economy. This transition, particularly concrete-to-concrete recycling, puts pressure on the availability of secondary materials for infrastructure. The road to a circular construction sector can therefore be better aligned and look at both buildings and infrastructure. This also applies to the industry, which supplies materials for both buildings and infrastructure. Better alignment is also relevant for standards and norms for building and infrastructure so that infrastructure will not be disadvantaged by regulations for buildings that do not fit in with infrastructure and the transition to circular infrastructure will not lag behind. An integrated approach is therefore required to maximise benefits. This is further elaborated in chapter 4. Since circular infrastructure has not yet received as much international attention as buildings, this publication focuses on positioning it more prominently.

The Sand Motor Aerial View, Source: Van Oord

Story of the first circular viaduct in The Netherlands

The first circular viaduct in the Netherlands is an ongoing project. It is a very interesting example for circular infrastructure as it illustrates a wide range of circular concepts (and challenges) in the field. It clearly demonstrates that to achieve a fully circular infrastructure, technical innovations are important, yet not enough. A clear vision and changes in the whole system, the rules of the sector and the way we work together on many different aspects and levels, are needed.

How it all began...

It all started when Esther van Eijk, the project leader at van Hattum en Blankevoort (vHeB), challenged her team before getting started with the construction of a new viaduct: Why not make it circular?

Esther is convinced that the way we currently design products should be changed and calls for new design strategies, 'waste is a design mistake'. Challenge accepted! A small group from various organisations (vHeB, Rijkswaterstaat, VolkerWessels competence infracenter, prefab-builder Consolis Spanbeton) gathered to explore what such a circular viaduct might look like.

In practice, viaducts in the Netherlands hardly reach their technical lifespan and are demolished much earlier for functional reasons. This led to the question of how the viaduct could be designed to allow for **re-use and/or adaptation to new purposes**? A series of brainstorming sessions followed.

> 'The main gain from the circular viaduct development process was not CO2-reduction, but the sharing of knowledge, not just with the partners, but with the whole sector. This enables the acceleration of innovation'.
>
> – Rob Valk, Rijkswaterstaat

The group was very excited about the potential of their innovative ideas and was eager to accomplish them in practice. That, however, was easier said than done. A grant application fell through, the intended location was no longer an option, and Rijkswaterstaat (the launching customer), initially struggled to raise funds and find a suitable way to allocate the project to the consortium due to procurement restrictions.

Eventually this was resolved by making the project a partnership, requiring it to be fully transparent and act as a safe zone for experimentation, sharing the results and lessons learned with the sector. An Open Learning Environment was created, a forum in which 60 participants from the various market parties, government agencies and research institutes shared know-how and experiences about the circular construction of viaducts.

Phase 1: Building the circular viaduct:

Almost two years after the initial idea came up, the project started with a construction team that gathered every week on 'Circular Tuesday'. The assignment was set: build the prototype. Regardless of the results, the most important thing was learning from the project and sharing the learning experiences. The contract was extremely concise and based on trust and mutual effort.

The group came up with a modular, scalable, de/re-mountable, and therefore fully re-usable solution. More specifically, a demountable bridgedeck, working with prestressing without attachment and 'shear keys'.

On December 4th 2018, 5 girders arrived at the Kampen site. 32 bars were fixed though the girders, a meticulous job. The main contractor was the first to successfully cross the viaduct in his car, followed by a large convoy of trucks and road vehicles.

On January 14th 2019, the circular viaduct was officially opened by the Minister for the Environment , Stientje van Veldhoven. A fully electric truck crossed the viaduct honking loudly of joy: “a short span, but a huge step for the circular economy” was rightfully displayed on a screen.

An environmental impact analysis of the viaduct was carried out on the basis of ECI (environmental cost indicator) and the principles of the circular measurement method designed by CB'23 Platform. The conclusion: the initial impact of the viaduct was greater than that of a conventional one. However, once the viaduct is used for a 2nd time, the score would favor the circular viaduct over a traditional one.

Another accomplishment along the process was winning the concrete award (Betonprijs 2019) in the ‘circular’ category’. The jury called it ‘an impulse for re-use of concrete constructions’.

At the beginning of September 2019, the circular viaduct was dismantled successfully and without damage in its original 5 girders. After being transported to a temporary storage facility at Consolis Spanbeton, one of those was also disassembled into the 8 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.

Key insights, lessons learned in designing, building, and monitoring, including all background information have been made accessible to anyone interested in a “learning history”. The experiences gained in building the first circular viaduct and using the Open Learning Environment have also been shared publicly and are used to move the development of circular viaducts further by means of a SBIR tender, together with the market parties.

Phase 2: SBIR circular viaduct

Despite the success of the first circular viaduct, which is 95% re-usable, it was clear that the mission for circular viaducts was far from being achieved. Further knowledge development and agreements were needed.

It was clear that conventional public procurement would not be enough to drive this development forward. A SBIR programme was therefore developed to stimulate the development of new innovations that, for example, Rijkswaterstaat could adopt as a launching customer. SBIR stands for Strategic Business Innovation Research, and is a procurement and financing method with which public organisations challenge entrepreneurs by means of an innovation competition to come up with products and services to solve societal challenges. The SBIR tender was set up using the insights from the Open Learning Environment, and the criteria were tightened up in a market consultation with other public organisations and market parties.

New solutions had to correspond to at least one of 3 categories: 1) Modular, demountable solutions, 2) solutions with high-quality reuse of existing released objects, components or materials 3) solutions based on renewable materials.

> ‘At this stage I think it is a good thing that so many different concepts and ideas get the opportunity to demonstrate their value’
>
> - Mark Huijbregts, prof environmental science, Radboud University

The SBIR was announced during the National Circular Economy Week in February 2020, and resulted in 32 applications, of which the best 10 were selected to perform a fully financed feasibility study. The jury reflected on a wide range of solutions: some focused on the use of circular materials such as wood, composite or circular concrete, while other projects focused on reduction of materials by changing the design.

Out of the 10 feasibility studies, 3 were selected to realise a prototype, based on (technical) feasibility, economic perspective and impact. Rijkswaterstaat will work closely with them in co-creation, and the knowledge community of the Open Learning Environment will be central to further knowledge development about circular viaducts. The goal is to make it open source. Consortia that provide an open licence will score higher. The other solutions will not be abandoned, but will be adopted by the transition path ‘civil engineering works’, as part of the national strategy ‘Climate Neutral and Circular Infrastructure’ by 2030.

See this link for a short video clip on how the circular viaduct project is being conducted.

Start of construction innovation strip 27-09-2021 Outgoing Minister Visser (Dutch Ministry of Infrastructure and Water Management), Nyckle Sijtsma (inventor of the innovation strip), Cees de Wijs (CEO VolkerWessels Infrastructure)

Chapter 3

The Dutch approach and best practices

The Netherlands is one of the countries with the most challenging terrains in the world. Most of its land lies on or are at below sea level and was reclaimed from the North Sea[29]. Tremendous efforts and infrastructure innovations have been put in building the thriving Dutch economy we see today. Through the Dutch triple helix approach of collaboration between the public sector, private sector, and academia, circular infrastructure innovations are continuously emerging. This chapter showcases some of the best practices that apply circular economy principles along the infrastructure value chain.

In this chapter we have sub-divided the best practices into the following categories:

- circular policies and practices
- circular procurement
- measuring circularity
- circular design strategies
- technical and material innovations
- material passports and data strategies
- circular business models
- circular market places
- supply chain collaboration, platforms and regional initiatives

Circular policies and strategies

In 2016, the Dutch government published a government-wide program titled 'A Circular Economy in the Netherlands by 2050'. This program introduces an ambitious target for the country, which is for The Netherlands to be fully circular by 2050. It defines five priority themes, which includes the construction sector. Separate transition agendas have been developed for each theme and are currently being carried out through yearly implementation programs.

https://www.government.nl/documents/policy-notes/2016/09/14/a-circular-economy-in-the-netherlands-by-2050
https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Circular-Construction-Economy.pdf
https://www.pbl.nl/sites/default/files/downloads/2021-pbl-icer2021_english_summary-4228.pdf

The transition agenda 'Circular Construction Economy', which was drawn up by a number of public and private stakeholders, describes the Dutch strategy of making the entire built environment circular by 2050. This includes residential and non-residential buildings, as well as infrastructure. The strategy sets an agenda for the period from 2018 to 2023 and a detailed description of the first steps to be taken in 2023, known as "the basecamp". A transition team, consisting of experts from different organizations and disciplines, leads the implementation of the transition agenda. They do so by working closely with other initiatives and organizations to achieve the goals set by giving solicited and unsolicited advice to the government, and by facilitating the transition.

In order to monitor and evaluate the progress towards a circular economy by 2050, a 'Work Program on Monitoring and Evaluation Circular Economy 2019–2023' has been set up. One of the important outcomes of the program is the bi-annual monitoring report, ICER.

In 2019, the Dutch Ministry of Infrastructure and Water Management and its two major executive agencies, Rijkswaterstaat and ProRail, put in place a specific target for infrastructure. Together they developed the strategy 'Towards climate neutral and circular infrastructure projects', which aims to be achieved by 2030. Among other goals, the strategy includes a 100% reduction of CO_2 emissions, high-quality reuse of all materials, at least 50% reduction in the use of primary raw materials, and minimal production waste. The strategy was developed along eight "transition paths'' for the most relevant projects and activities with the greatest environmental impact. It also includes a proposal for a financial model to be incorporated in project plans (tenders) and budgets. The strategy is now being extended to all other local and regional authorities to embrace the entire infrastructure sector. Part of the Dutch ambition is for all public tenders to be circular by 2030.

Circular procurement

Circular procurement indicates the usage of the right purchasing instruments to drive the circular economy. For each circular solution, it is important to evaluate the most suitable contract form, award criteria, and contract requirements. A powerful tool used for circular procurement in the Netherlands is the environmental cost indicator (ECI). This is an indicator based on the European norm EN15804, which monetizes environmental costs on the basis of shadow-prices. By awarding a virtual reduction for offers with a better (lower) ECI, the market is encouraged to develop and offer alternatives that are more circular. DuboCalc is an example of a software tool that is used by infra providers and (potential) contractors to calculate the environmental impact of a material, structure, or construction method. With this tool, the entire life cycle, from material extraction to demolition is taken into account. Another similar tool is the Dutch National Environmental Database Foundation (Stichting NMD), which is an independent environmental database that stores environmental data about building materials and installations, and maintains and guarantees the quality of the determination method. This determines the environmental performance of buildings and infrastructure projects.

Buyer groups

In a buyer group, contracting authorities in the public and private sectors work together to develop a shared market vision and strategy for a specific product category to make the market more sustainable. This gives a clear signal to the market and encourages it to develop sustainable solutions that respond to a clear and common need. The members of the buyer group aim to implement this vision and strategy in their procurement practice within two years.

For example, participants engage in market dialogues, learn from each other's experiences and work together to develop specifications and reward criteria. Other commissioning parties can join and apply the strategy themselves when they are ready. This enhances the collective impact.

Within the Dutch infrastructure-sector, following successful initiatives in Sweden, Norway and the EU, buyer groups have been appointed for:

- zero-emission building materials
- low-CO2 concrete
- sustainable road surfacing
- circular signage
- circular viaducts
- climate neutral dredging

For more info: Buyer groups for sustainability | PIANOo - Dutch Public Procurement Expertise Centre

Stichting BouwCirculair, Moederbestek

Moederbestek.nl is a site from BouwCirculair (Dutch Circular Construction Network) that supports mostly smaller, local procurers in circular procurement by providing minimum requirements for contracting. The site offers ambition documents, product sheets, and uniform specifications for concrete and asphalt.

moederbestek.nl

Circular road furniture, Rijkswaterstaat

Several overviews of circular products and materials on offer have been made for procurers and builders to have easy access to information, thus stimulating both offer and demand. Interesting examples include the database circular road furniture, a result of a launching customer project in which Rijkswaterstaat 1) stimulates the use of existing, (e.g. re-used) alternatives, 2) had new products developed, e.g. Bio composite with grass and reed from Rijkswaterstaat grounds and 3) new circular designs. The database contains examples of 11 product types, a.o. circular road signs, guard rails and portals, with a description of the level of circularity (circular strategy and LCA data), market readiness and TRL (technology readiness level).

Rijkswaterstaat
Ministry of Infrastructure and Water Management

Circular Procurement in 8 Steps, Copper8

'Circular Procurement in 8 Steps' is a generic guideline by Copper8 to facilitate organisations in circular procurement. A specific version 'circular procurement in 8 steps for construction' has been developed for the transition team circular construction economy and focuses on infrastructure.

Copper8 De circulaire bouweconomie

Measuring circularity

Measuring circularity is important for many decision-making processes. For example, it can play a role in tenders or in monitoring the circularity performance of a country. To provide insight into the degree of circularity of a material, product, structure, or area, a uniform and effective measurement method is indispensable. The CB'23 Platform (Circular Construction in 2023 Platform) has worked on a core method for measuring circularity; harmonizing and expanding on existing methods. The core method is based on the three key goals of circular construction: 1) to protect stocks of materials, 2) environmental protection, and 3) value retention. This is described in the guideline 'Measuring circularity in the construction sector'. The measurement methods for the first two goals are established and ready for use, while the third is being developed. The method will be implemented in the national environmental database (described in the 'circular procurement' segment above), and has already been tested in projects. It is currently being improved upon and made more accessible for use. The development of a method to determine the third goal, value retention, is the main focus of the action team in 2021-22.

An important aspect of circularity is also whether parts and components (or structures as a whole) can be disassembled with ease and without damage. The better the de-mountability, or detachability, the higher the chances are for high-value re-use. A method to establish de-mountability has been developed for buildings: 'Circular Buildings - a measurement methodology for detachability v2.0' (Dutch). It is still being improved, and it serves as a starting point for an adaptation for the infrastructure (as part of construction).

Circular design strategies

Circular design is about carefully considering the entire life cycle of an object from the beginning until the end. This is imperative especially when designing a large scale structure, such as a highway or a viaduct. It takes into consideration aspects such as the desired lifespan, the future (re)use of all parts and materials, and the usage of various types of (sustainable) materials. Circular design also takes into account maintenance and potential (functional) changes in the future of the structure. CB'23 Platform has published a guideline on circular design (in Dutch). It underlines the fact that there is no "one size fits all" circular strategy, and that a customized approach is needed for each design challenge. The guideline identifies 6 main strategies, which, in varying composition, form a sort of methodology for approaching specific design challenges. It also highlights that traditional roles and collaborations change in a circular system, and introduces the concept of a design-ecosystem that replaces the traditional design-chain.

Several studies have been performed to illustrate examples of circular design strategies in practice and identify potentially promising measures to realize circular infrastructure:

- IPV Delft has compiled an Inspiration book on circular design in the infrastructure sector (in Dutch), in which the most important design principles and strategies are illustrated based on real-life projects.
- RHDHV has researched several circular objects (in Dutch), such as bridges, dykes, locks and roads, and the potentially most suited design strategies and measures.

Circular design can be inspired by nature, whether it be product/service design or process design. Natural forces such as wind and sea currents can be harnessed not only for energy generation, but for assisting the process of distributing materials to serve a specific purpose.

EcoShape, Sand Motor – building with nature in the circular economy

Every year about 12 million m^3 of sand needs to be replenished to protect and preserve the Dutch coast lines. It is expected that this volume will increase in the coming decades due to the rise of sea-level. Adding to that, sometimes a heavy storm can be enough to undo the suppletion.

Commissioned by the Dutch Ministry of Infrastructure and Water Management Works, a so-called Sand Motor project was initiated on the coast not far from the city of The Hague. By supplementing a huge amount of sand (over 20 million m3) extracted offshore and deposited along the coast in a single operation, a hook-shaped peninsula was created as a buffer against the rising sea level. By making use of natural processes to redistribute the sand over time, the Sand Motor was expected to nourish the coast with sand for about twenty years. Until today, no additional replenishment was needed for this location.

Building with nature fits perfectly well in a circular economy. By learning about and monitoring natural processes, coastal protection requires less scarce resources such as fossil fuels for vessels. By making use of natural conditions, sand can be transported in the right direction, resulting in an effective and sufficient protection of the coast. This project is an inspiration for new research and projects. Other examples include the mud-motor, the construction and natural management of new dunes, and the rediscovery of traditional land reclamation techniques by making dams with poles and bundles of willow wood as a natural protection against coastal erosion.

For more information: ecoshape.org/en/pilots/the-delfland-sand-engine-4

For a better idea on how the Sand Motor project was developed and how it works check out these two short movies: movie 1 – movie 2.

Maintenance at the Sand Motor, Source: Van Oord

Technical and material innovations

Circular innovations along the value chain of infrastructure are the on-ground manifestation of circular design methods, policies, strategies, and the cooperation between the stakeholders involved. In The Netherlands, innovations in materials, products, components, and processes are changing the landscape of the industry and playing an important role in achieving the country's ambitious circularity goals.

Wastewater treatment has an important role to play in a circular economy. The Dutch water authorities are innovating in wastewater treatment plants and transforming them into factories for clean water, energy, and raw materials that can be used in many applications including construction and infrastructure.

A good example is the extraction of Kaumera during the water purification process, as showcased on the next page

SmartCrusher BV

The concrete industry on a global scale is 3 times more polluting than the aviation industry. This is mainly due to the production of cement from CaCO3, whereby for every kilogram of cement, one kilogram of CO2 is released. The SmartCrusher can decompose concrete rubble into its constituent parts, i.e., undamaged sand and gravel, and the cement fraction can also be removed. The recovered sand and gravel can be reused immediately and give even better results. The recovered cement can serve as a CO2-free raw material to make new cement and can also be used as a concrete improver.

For more information: smartcrusher.nl

SmartCrusher bv
We close the circle


P
bus
bus

Kaumera Nereda® Gum

Kaumera is a biobased exopolymer with multifunctional properties. It is extracted from the sludge granules that form during the Nereda® water purification process. In October 2019, the first full scale installation in the world was completed in Zutphen, the Netherlands. A second installation in Epe has been operational since 2020.
Kaumera is a versatile raw material that can be used as a substitute for petrochemical materials in many applications. It can repel and absorb water and it is fire retardant. It is also very suitable as a binding agent for coatings and composite materials. By combining it with other raw materials, the character of the fabric changes.

Various applications of Kaumera are currently being developed. In agri- and horticulture, Kaumera is used as a bio stimulant, or it is used as the main ingredient to produce a slow release coating for fertilizers. Also, by combining Kaumera with for example clay or cellulose, unique bio composite materials can be produced.

For more information: kaumera.com

kaumera
nereda® gum

Project Chaplin

CHAPLIN aims to contribute to the sustainability of road construction. The project is a result of a unique collaboration of partners along the entire value chain. The companies (road builders, asphalt producers and lignin suppliers) are supported by research and technology parties. Rijkswaterstaat, provinces and municipalities are heavily involved as road authorities, and they are committed to the development of lignin-based asphalt into a fully commercially available and specified product. Lignin is a substance that is a natural binder and gives strength, as it does in plants and trees. When plants and trees are growing, carbon dioxide is absorbed from the atmosphere and once processed into asphalt, it is fixed in the road for a long period of time. An additional advantage is that lignin offers road builders an alternative raw material to bitumen. Improvements in petroleum refining processes are putting the quality and availability of bitumen as a by-product under increasing pressure. CHAPLIN, thus, supports the transition to a circular economy through biomimicry, increasing durability, sourcing from renewable and natural materials, as well as keeping carbon out of the atmosphere.

For more information: biobaseddelta.nl/topics/chaplin

CHAPLIN

AsfaltNu, BAM Infra - LE2AP

The paving industry has a lot to contribute to halting climate change. Asphalt is normally produced at approximately 165°C and typically the layers contain little or no reclaimed asphalt. To change this, AsfaltNu developed Low Emission2 Asphalt Pavement (LE2AP). LE2AP asphalt is high-quality asphalt produced at 105°C, mainly comprising materials recovered from old asphalt. LE2AP asphalt reduces the use of raw materials and energy, helping road authorities to reach their sustainability goals. In the LE2AP production process old asphalt is first separated into a bitumen-rich mortar fraction and bitumen-poor stone fractions. Only the mortar fraction requires treatment and is heated to 165°C to be brought to specification. The mortar is then mixed with the stone fractions at approximately 100°C. Since 2016, AsfaltNu has produced both LE2AP Stone Mastic Asphalt and LE2AP noise reducing Porous Asphalt surface layers. AsfaltNu is currently designing a CO2-emission free asphalt plant where LE2AP asphalt can be produced at a large scale.

For more information: asfaltnu.nl & bamle2ap.com/en

ASFALTNU
VOOR MORGEN

Life

Circular Wooden Bridges, ARC2 & Meerdink Bridges

Circular Wooden Bridges: 'An environmentally friendly, sustainable and contemporary bridge concept'

Circulaire Houten Bruggen (Circular Wooden Bridges) is an environmentally friendly bridge concept developed in collaboration between the two Dutch companies, Meerdink Bridges and the architectural firm Arc2 architects. The starting point was to achieve circular use of raw materials for the construction of a circular bridge depending mainly on recycled hardwood from discarded parts. Through 'Urban-Mining', the raw materials are obtained from, among other things, hardwood sheet piling, lock gates, bollards, railway sleepers, and old bridge parts. These materials are carefully collected and introduced to the new contemporary and functional designs.

Old wooden parts are usually seen as waste and are often incinerated for energy recovery after discharge. Through this circular method, the hardwood gets an extra life. Less virgin wood needs to be cut and considerable CO2 savings are made. A number of great examples of circular bridges have already been realised based on this sustainable concept.

For more information: arc2.nl

arc² architecten

Meerdink Bruggen

Grasfalt, NTP

Grasfalt is an innovative asphalt mixture where bitumen is replaced by the bio-based binder lignin, which comes from elephant grass and allows for:

- Savings in fossil resources;
- 20% CO2 reduction from the lower production temperature of Grasfalt (130°C instead of 170°C), which saves more than 2 m³ of gas per ton of Grasfalt;
- Sustainable storage of CO2 through elephant grass, which absorbs up to 4 times more CO2 than trees!

For each hectare of elephant grass (which accounts for 3.2 tons of lignin) 26.4 tons of CO2 is absorbed per year. In the current Grasfalt mix, 50% of the bitumen is replaced with lignin from elephant grass. Grasfalt is currently under further development with the goal of 100% replacement!

For more information: ntp.nl/duurzaamheid/grasfalt

NTP miscancell

Circular business models

A long-term perspective and clear responsibility for products and materials is essential in a circular economy. Because the durations of contracts in infrastructure are quite short – only a fraction of the lifespan of the assets concerned – short term agreements are mainstream. This hinders the development of circular solutions. Therefore, it seems worthwhile to explore whether these barriers can be removed by offering infrastructure as a service (IAAS): a concept in which the contractor assumes (part of the) responsibility and is stimulated to make long term considerations about design, construction, maintenance and replacement. Applying infrastructure as a service is a complex process due to the combination of a long life span of the assets and the relation between one customer (the public organization) and a competitive field of suppliers. Being able to determine residual lifespan and residual value is very important. The shift in roles between public organizations and contractors can also be a challenge.

The circular road (DCW): another business model for real circular infrastructure?

DCW is a partner program between a builder (Dura Vermeer), 3 councils and 3 provinces, knowledge partners and the Delft University of Technology. It explores in 7 actual projects whether or not the application of IAAS leads to more circularity, and which barriers for application need to be removed. Testing the concept in different pilot projects with different assets, ranging from lighting to roads and bridge decks to guardrails, helps identify the situations in which IAAS can stimulate circular construction. The partners decided to share results with the sector when they become available (expected mid 2022) in order to enhance circularity.

Through real life projects, the partners experience how cooperation works within this business model, and which (new) roles are useful. Sweco analyses the lessons learned relating to procurement and cooperation. Important (intermediate) conclusions are:

- In IAAS the design process is focused on value creation as a result of the lifecycle-approach.
- If all (financial) information is available, it is possible to reach a solid, positive business case.

The pilot with light as a service in the province of Noord Brabant was successfully transformed from pilot to full project. In phase 1, 55% energy reduction was achieved, the lifespan of light fixtures increased by 5-10 years, and it resulted in an overall positive impact on biodiversity.

For more information: decirculaireweg.nl/the-circular-road-en/

De Circulaire Weg

In the report 'Circular Infrastructure Business Models, Insights from the Open Learning Environment Circular Bridges and Viaducts' by the Platform for Accelerating the Circular Economy (PACE), 4 alternative and circular business models for infrastructure are defined.

1. Coordination of modular infrastructure by a government agency,
2. Buy-back guarantees by infrastructure companies,
3. Viaduct As a Service, and
4. Infrastructure companies and its clients jointly operating in consortia ('All-in Consortium')

Materials passports and data strategy

A materials passport is a digital database recording the objects in buildings or infrastructure. It documents what they consist of (in both qualitative and quantitative terms), how they were built, where they are located, and the ownership of the entire object and/or its parts. Materials passports are an important means for achieving circularity in the infrastructure sector since they promote high-value reuse at the material, product, element, and building levels. In the Netherlands, practical experiences in the infrastructure sector have been gained from the Materialenexpeditie (materials expedition) and Madaster. However, collecting the needed data raises many questions and challenges on several levels. These questions include: What information is needed to enable and safeguard circular decisions? Is this information different for structures at different stages of their life cycle, i.e., new construction, maintenance or demolition? In addition to these questions concerning the right information to incorporate in a material passport, there are also questions regarding how data should be collected and stored. For instance, should it be stored in a central database and/or at the source using linked data? Which formats should be used? How to make sure this happens in a secure manner that guarantees availability and continuity to those who have access? To answer these questions, a sector wide strategy is called for.

CB'23 Platform has developed a guideline 2.0 for 'passports in the construction sector'. It describes various types of passports depending on the scale that is being considered (structure, product, and element/object) as well as the lifecycle it is used in (new building, maintenance, demolition). The guideline contains a 'long list of passport items' which lists all items (depending on the passport type and intended use) that can be included in a passport including the unit and form in which they should be recorded. It is subdivided into items for structure, product, and element/object. It also describes preconditions, issues, and focus areas in data governance.

Madaster is the online registry for materials and products. On this digital platform, buildings are registered, including the materials and products that were used in their construction. Madaster is mainly focused on buildings, but efforts are made to include infrastructure and its specific requirements. Recently an environmental register pilot project started in Amsterdam, in which all kinds of infrastructure are stored.

Materials expedition, practical experiences with material passports

A group of both builders and public organisations wanted to learn more about materials passports in the infrastructure sector, in order to speed up their application. In 'materials expedition 1' they gathered practical insights in 14 pilot projects and shared and analysed their lessons learned.

A second materials expedition helped gather information on specific issues, to help policymakers better understand if materials passports could and should be a legal requirement. Action research was conducted to understand the specific needs for information, whether a materials passport would lead to more circular behaviour/results and if there are any alternatives for a passport.

It was concluded that material passports can play an important role in the unambiguous query and storage of object and material information. Thus, it can be an important precondition to facilitate future reuse and enable more effective (asset)management and maintenance. The most important next step is to develop a system for data sharing within the sector. Standards should be developed, including formats, data sources, accessibility and interchangeability. Thus, the 2 material expeditions show how different parties joined forces in order to find answers on the role a materials passport could play in a Circular Economy, and what challenges should be tackled.

Bouwend Nederland · DURA VERMEER · TBI · provincie Overijssel · VolkerWessels · Provincie Noord-Holland


Boskalis

Circular marketplaces

Coordination and cooperation within the chain is crucial for good infrastructure and construction logistics. Conditions for the successful execution of logistics for infrastructure and construction include insights into the integral chain costs, joint tactical and operational plans based on shared information, sufficient scale in circular marketplaces to reduce costs, a well-thought-out location of the marketplaces, insights into the operational logistics performance, and an active role of local government in tendering and licensing.

Typical activities in circular marketplaces include:

- Supply of bulk raw materials
- Production of bulk building materials
- Storage of bulk building materials
- Distribution of bulk building materials
- Demolition & waste separation
- Processing / reprocessing of construction and demolition waste into secondary construction material

Excess Material Exchange (EME)

EME is a young and innovative company offering a digital match-making platform that enables companies to find new high-value reuse options for materials or (waste) products. As a pilot, they explored the viability of the Excess Materials Exchange as a “dating site” for secondary materials in order to help companies transition to a circular economy by creating a scalable market (including a market price) for secondary materials.

For more information: excessmaterialsexchange.com/nl/pilot-report-release

National Bridges Bank - a digital marketplace for bridges and bridge parts

The Nationale Bruggenbank (National Bridges Bank) is an independent platform where supply and demand of used bridges come together, from governments for governments. The National Bridge Bank is an initiative launched in March 2021 by AmRoR, a collaborative alliance between Rijkswaterstaat and the municipalities of Amsterdam and Rotterdam, and the Bridge Foundation. This is a new platform that shows which bridges are available for reuse and brings supply and demand together. The platform ensures less energy and material consumption by preventing new bridges to be built. Various government bodies showed their interest in the bridges, as well as the components of the bridges that are available on the platform. In order to facilitate the process of reuse, the guideline ‘reuse of bridges (Dutch)’ has been developed and made available.

For more information: nationalebruggenbank.nl

INSERT

Insert was founded in 2018. Together with 12 demolition companies, they started building an online marketplace with the aim of providing insight into reusable buildings and raw materials.

This goal has been expanded to also give visibility to circular opportunities in the green and civil sector. Together with partners, they work on sustainability, reducing waste, preservation of primary raw materials, and reducing CO2 emissions.

In demolition and renovation projects for buildings and public spaces, such as roads, streets, neighbourhoods and parks, enormous amounts of materials are often replaced. Many of these materials are still easily reusable, either one-on-one, or with small adjustments. Reusing them can save primary raw materials and reduce the emission of harmful substances such as CO2 and nitrogen.

For more information: insert.nl

Supply-chain collaboration, platforms, and regional initiatives

It goes without saying that collaboration is essential for the transition to a circular infrastructure. In the Netherlands, **supply - or value - chain initiatives -** such as the Concrete Agreement (Betonakkoord) and the Asphalt Impulse are examples of how stakeholders in the supply-chain work together to make materials more sustainable. The wood value chain coalition for infrastructure has the ambition to make wood an equal alternative for steel, concrete, and plastic in the materials mix for infrastructure. Another example is the recently launched National Steel-Agreement.

In addition, there are **platforms** to create awareness, promote and share knowledge developments, provide tools and practical insights, such as Cirkelstad.

CIRCO – with support from the Dutch government – activates entrepreneurs and creative professionals to (re)design products, services and business models in order to subsequently conduct business in a circular way. In 3-day Circo-tracks, entrepreneurs and industry professionals are challenged to use circular design strategies to redesign their own propositions, products, services and business models, and identify business opportunities. This results in a concrete implementation roadmap. Research shows that 66% of the CIRCO participants have implemented their new circular propositions.

Bouwcirculair is a network of over 200 organisations focused on the use of sustainable materials in construction projects, specifically concrete, asphalt and greenery. The network brings all parties together in the construction chain and organizes meetings, initiates projects and testing grounds, and develops instruments from a very practical perspective.

A specific type of platform is **CB’23 Platform**, which aims at bringing together professionals from the entire construction sector to establish joint and unambiguous agreements on important topics in circular construction and to describe these in its guidelines.

A third important type of initiative is that of regional collaboration, since the regional level is very important for circular strategies such as closing material loops. The MRA (Amsterdam Metropolitan Area), consisting of 32 municipalities, two provinces (North Holland and Flevoland) and the Amsterdam Transport Authority, is an example that shows the power of regional cooperation. It works on 3 program lines: circular procurement, material flows, and circular area development. This resulted in, among other things, the roadmap circular procurement, which is a practical guideline that enables MRA stakeholders to reach their circular procurement ambitions. Another example is Friesland Circulair, which is an active and open network started by local businesses and expanded to over 100 organisations. As a result, all Friesian public bodies and large knowledge institutions have joined forces to make the province of Friesland the most circular region in Europe. They are active in 11 areas, among which experts are used as ‘boosters’ to support businesses in their circular efforts.

The Concrete Agreement (Betonakkoord)

In response to the alarming environmental problems, frontrunners in the concrete sector have joined forces with the government, as well as with the building and recycling sectors and research institutes to formulate the ‘Dutch Concrete Agreement in 2018’. The aim was to reach ambitious environmental and social goals and steer the concrete sector into a sustainable direction. A network of partners has jointly managed to develop roadmaps on CO2 reduction, net positive value of biodiversity, circular design and 100% circular use of concrete being demolished. To accelerate the introduction of more sustainable solutions, the frontrunner approach is leading. This means that the sustainability results gained by frontrunners (expressed in the Environmental Cost Indicator) will be the standard for the peloton in due time. The Environmental Cost indicator will be integrated in the procurement guidelines and become stricter in the course of time. The challenge ahead is to mobilise the whole concrete sector in the scale up phase to act according to the Concrete Agreement.

For more information contact: communicatie@asfaltnu.nl or visit: www.betonakkoord.nl

Cirkelstad

Cirkelstad ('Circular City') is a cooperative organization, organized in Circle-cities and bringing together frontrunners in the circular and inclusive building sector. Cirkelstad partners meet to exchange knowledge, discuss cases, best practices, and support each other in Communities of Practice. These Communities of Practices are organized 4 times yearly in various Circle-cities, each of which is coordinated by a 'spinner'. In addition, several overall activities are undertaken:

- A bi-weekly City newspaper is published
- The Cirkelstad Academy offers tools and knowledge on circular construction
- A product database offers an overview of circular products

<u>Accelerate together</u>
The national and regional program 'Accelerate together' aims to reach a covenant in 2023 that describes 'circular construction, the new normal'. To set up the covenant, participants audited each other's (100+) projects, contributing to a better understanding of circular construction, setting the bar, and disseminating tools and tips over the course of 3 years.

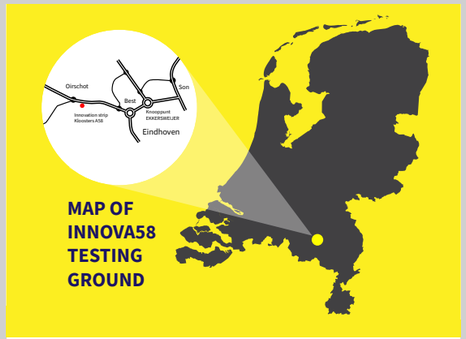
For more information: cirkelstad.nl

CB'23 PLATFORM (Circular Construction 2023)

The shift to a circular construction economy requires a package of unambiguous agreements to anchor circular thinking and actions in daily construction practices. CB'23 Platform is committed to drafting these agreements for the entire Dutch construction sector, which includes both residential and non-residential construction as well as civil engineering. Teams consisting of professionals from different parts of the Dutch construction sector have laid a solid basis for circular agreements on important circular topics. At this stage, they essentially are working according to agreements and guides, rather than formal standards.

The Circular Construction Lexicon serves as the starting point. The necessary transformation of the supply chain, i.e., the underlying procedural change that is needed, is the other connecting factor. In July 2020 CB'23 Platform launched the 2.0 versions of a Lexicon Circular Construction and two guides about measuring circularity in the construction sector and about passports for the construction sector. In July 2021 CB'23 Platform launched two new guides (in Dutch): one about circular design and the other about Circular tendering. In 2021-2022 the platform is working on the guidelines for future re-use.

For more information, contact info@platformcb23.nl or visit the website www.platformcb23.nl



RWS & KWS, Innovation strip A58 Kloosters rest area, the Netherlands

Rijkswaterstaat and civil engineering company Gebr. Van Kessel/KWS, which is part of VolkerWessels, are testing sustainable innovations in road construction in an unusual way. Their focus is on circularity and CO2 reduction, and they are using the innovation strip along the A58 motorway to do this.

The innovation strip has double entry and exit lanes that are each 1,400 meters long. It is the only test strip in Europe that is accessible to regular traffic, making field testing possible.

<u>Zero emission construction site</u>
The innovation strip is being built with no CO2 emissions and in accordance with the Tank-to-Wheel principle. With the slogan 'Getting rid of CO2 together', Gebr. Van Kessel is using electrical equipment and machines that run on clean fuel. The chain park is fitted with a hydrogen generator.

<u>Circular products</u>
In addition, Gebr. Van Kessel and its cooperation partners are promoting circular products and their own innovations, such as: 80-100% circular low-temperature asphalt, biobased/circular road furniture and markings, circular water storage facilities and naturally bonded foundations.
In September 2021, the Minister of Infrastructure and Water Management gave the go-ahead for the construction of the innovation strip. The strip is planned to be completed in the summer of 2022.

For more information: samenCO2wegwerken.nu and innovA58.nl

Direct contact: iska58@kessel.nl or innova58@rws.nl

Arrosso - circular guardrails

The Dutch company Arrosso has developed a method to successfully reuse galvanized guardrails by dismantling, stripping, de- and regalvanizing them, with circular recovery of zinc.

Arrosso has carried out projects for both national and local government, along motorways and local roads. Practical and economic feasibility has been demonstrated in several practical tests. Thus, the method of dismantling the guardrail improved and more guardrails are available to be reused. It is also attractive that the total cost of reuse is below that of a new guardrail.

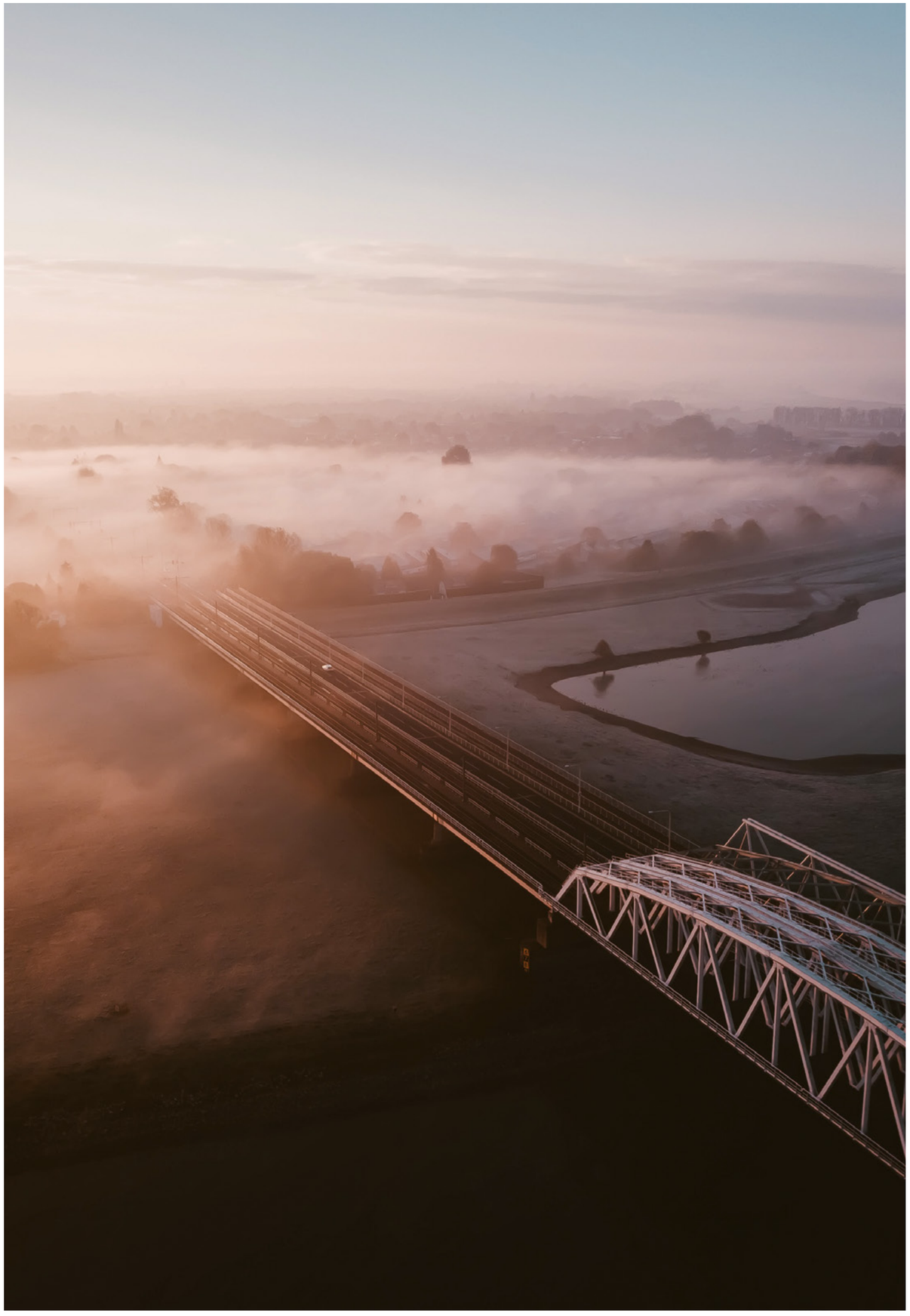
Scientific tests accompanied by leading materials engineers and professors have proven that the controlled reuse of galvanized guard rail has no adverse effects on the capability of the guardrail.

After disassembly of the used guardrails, each single part is checked for shape, thickness, damage, corrosion and steel type for critical parts. Material properties are confirmed by tensile and notch impact tests on specific samples.

Since 2008 Arrosso has renovated 280 km of guardrail, saved 9,800 tons of steel production, saved 100,000 MWh of energy and 17,750 tons of CO2-emissions.

For more information: rwsinnoveert.nl

Source_ Kaumera - Raw material plant, site in Zutphen, The Netherlands



Chapter 4

Proposal for an international action plan circular infrastructure

1. The momentum to act is now

The time is now to jumpstart the transition towards circular infrastructure. Various actors across the globe are detailing ambitious infrastructure plans: the European Union (EU) recently agreed on an infrastructure plan similar to China's new Silk Road, President Biden reached a deal for mega investments in the U.S. infrastructure and the G7 launched the Build Back Better World (B3W) initiative. A wave of infrastructure projects renovations, replacements and new constructions is expected in the coming years.

There is a growing consensus on the urgency to act. The COP26 in Glasgow made this abundantly clear. This calls for circular infrastructure comes from governmental organisations as well as the business community.

In Europe, current policy developments can also be a major driver for circular change, if done right. Circular infrastructure can greatly benefit from this and should be a central theme in upcoming programs and initiatives.

With the European Green Deal the EU wants to reform its economy to achieve net-zero emissions and resource-free economic growth by 2050. The Circular Economy Action Plan (CEAP) is one of the building blocks of this deal. Construction and buildings are identified as one of the key sectors in the CEAP. Infrastructure offers opportunities to reach the goals set in these initiatives.

In 2020 the European Commission (EC) committed itself to develop a Strategy for the Sustainable Built Environment in the CEAP and Industrial Strategy. The presence of such a strategy could encourage widespread adoption of important tools (from changing legislation to digital logbooks) to promote circular infrastructure. Although the delivery of the strategy has been delayed, more and more stakeholders seek to contribute to its development and are calling for its implementation. The EC has also developed a policy agenda on sustainable finance, including the Action Plan on Financing Sustainable Growth. The core of the plan is the EU Taxonomy Regulation, which could have a big impact on circular infrastructure.

More recently, the Fit for 55 package has been published, charting the way towards a more carbon neutral Europe. It sees infrastructure as an important supporting sector to achieve this. The EC also recently adopted the technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. It stipulates that the operation, maintenance and final decommissioning of any project should be carried out in a climate-neutral way, which may include circular economy considerations, such as the recycling or repurposing of materials.

These global developments can help to unlock the potential of circular infrastructure. In the following section, we propose a multi-stakeholder Action Plan that calls for international cooperation to accelerate the transition to circular infrastructure in the global run towards a climate neutral and circular economy. This proposal for an Action Plan explores what is needed to realise the transition to circular infrastructure across borders.

This Action Plan acknowledges that many actors will need to play an important role in deploying a circular infrastructure: from private and financial, to public and knowledge actors. However, as public clients dominate the infrastructure sector, this Action Plan focuses mainly on public policies and the public side. In addition, while many of the proposed actions focus on Europe, most are also worldwide applicable.

2. Action agenda: how can circular potential in infrastructure be unlocked?

2.1 We need to go circular together

International cooperation is paramount to unlock the infrastructure's potential for achieving climate neutrality and a circular economy. After all, supply chains span several countries and depend heavily on international raw material flows. Cooperation across supply chains and international raw materials markets, like those for cement and steel, will help the construction industry achieve climate and circular economy goals.

National governments, the EU and other relevant inter- and transnational organisations and forums, such as the United Nations Environment Program (UNEP), Organisation for Economic Co-operation and Development (OECD), the G7 and G20 should increase efforts to promote and support international collaboration for circular infrastructure.

Bilateral and/or regional collaboration between countries and (similar) organisations should be further promoted and supported. In Europe, such partnerships already exist. For example, between Rijkswaterstaat (RWS) in the Netherlands and the Public Waste Authority in Belgium (OVAM), who work together on circular procurement; and the European Environmental Agency and the Environmental Coalition on Standards, which are pushing for the delivery of the EU Strategy for a Sustainable Built Environment. There are many ways bilateral and regional support can be fostered to encourage uptake of circular economy principles in the infrastructure sector. Some ideas include:

- **Setting up dedicated value chain collaboration programs** (e.g., programs that focus on closing material loops that are handled at an international level, like concrete or steel) and Materials Agreements (e.g., similar to the Dutch Concrete Agreement or 'Betonakkoord').

- **Setting up common knowledge & innovation development projects**, such as the European project Building As Material Banks (BAMB2020) for the built environment.

- **Connecting stakeholders** in the infrastructure sector with climate neutral and circularity platforms, such as the European Circular Economy Stakeholder Platform (ECESP). In those platforms, frontrunners from both private and public sectors can interact with similar organisations, learn from each other and exchange best practices and information.

2.2 Set the right frameworks for climate neutral and circular infrastructure

In addition to international cooperation, policy can support unlocking the potential of circular infrastructure. In Europe, for example, the proposed Strategy for a Sustainable Built Environment, for example, could help accelerate the development of a circular infrastructure.

An integrated approach to circular construction is needed...

...where buildings and infrastructure are evenly addressed to maximize the benefits. After all, these sub-sectors are highly interdependent in terms of material flows, supply chains, standards and norms, and share many similarities like how circularity can be designed and measured. However, certain characteristics differ and addressing them in construction policies, tools etc. is essential to provide optimal opportunities for circularity. In this way, both infrastructure and buildings will be advantaged by new policy opportunities. In Europe, for example, the forthcoming revision of the Construction Products Regulation (CPR) and extension of the Eco-design Directive could be relevant to offer these opportunities.

In the Netherlands both the infrastructure and buildings sectors work on common circular economy approaches, such as: measurement methods for circularity; materials passports, circular use of materials, etc. Together, these sub-sectors are also making sector-wide agreements, developing coherent guidelines and frameworks through the national CB'23 Platform. By tackling the transition in an integral way, for example, the combined volumes become a strong incentive for the industry to innovate and switch to circularity.

Systematically include infrastructure issues in the elaboration of relevant policies and programmes

Infrastructure influences and is influenced by a number of topics, i.e.: construction (same companies, materials, and techniques), waste policies (allowed usage of waste products), mobility (different types of vehicles, more load for bridges), climate policies (reduction of GHG emissions). Actions are therefore needed to systematically include infrastructure issues in the various policy programmes of these topics.

Set-up a coalition of the willing and of the doing for a common circularity framework

We need to start including infrastructure into existing programs and policies at national and international level and we need a specific framework (protocols, norms, etc.) for circular infrastructure.

To create a common circularity framework for the infrastructure, relevant stakeholders could mobilize the setting up of a "coalition of the willing" through existing platforms, such as the European Stakeholder Platform. It could consist of a number of Member States (MS), market parties and other international organizations, such as the UNEP with its Sustainable Buildings working group. The coalition could work on innovations/technologies for e.g., high-quality recycling, renewable materials, data management or how to make specific criteria for procurement of circular infrastructure.

In addition, "coalitions of the doing" could be set-up by various stakeholders (individual MS, relevant NGOs, knowledge institutes, etc.) and at different levels (local, regional, national and international). They can take immediate action by learning from each other (sharing best practices), making specific transition pathways at an international level (e.g., transition to circular concrete, making dredging more circular) and aligning specific sub-sectors or product categories in infrastructure (e.g., road signs and infrastructure works). These coalitions of the doing can start by directly trying to shape the directions of their fields. They can work on and adopt cutting edge practices like material passports and circular procurement. These coalitions could also make use of existing instruments and programmes, such as the Big Buyers Initiative.

One successful example of a "coalition of the doing" is the "Circular & Fair ICT Pact", which was set up by nine front runner countries on their own.

These types of coalitions can give the market perspective and help in making investment choices, as they operate at a higher level than individual organizations and countries.

Enhance circularity through common protocols, norms, standards and harmonization of circularity measurement methods

It is relevant to have common protocols, norms, standards and harmonized definitions to ensure coherence and clarity. It is also necessary to have common quality requirements, certification and track & trace systems to give the market confidence for the safe use of recycled materials. This requires uniformity on a larger scale to actively stimulate circularity in the infrastructure.

Furthermore, it is important to work on a single integrated measurement method for sustainability and not on methods that focus only on one aspect, for example CO2. There should be one calculation method based on the existing standards, e.g. EN 15804, from the European Committee for Standardization (CEN – an organization which provides an efficient infrastructure to interested parties for the development, maintenance and distribution of coherent sets of standards and specifications).

The integrated method should steer clear from a purely weight-oriented focus (e.g., a parameter that says at least 50% of total weight needs to be recycled), but also look at individual material streams, eco-design and actual climate impact.

With regards to measuring circularity, the Construction Products Regulation should be at the forefront of product information to ensure coherence. The CPR is currently under review and the new version should take into account that the environmental performance of construction products and materials cannot be assessed stand-alone, but in the context of an entire construction project. In the CPR, the EU should stimulate the use of Environmental Product Declarations (EPD) for life cycle assessments of construction works, based on existing CEN standards. There is room in the current European Standards to include circular infrastructure (more focus on circular (re)design, recycling, disassembly).

Furthermore, life cycle approaches and circular economy design principles used for buildings should be extended to infrastructure works. This could be similar to the EU Level(s) framework for buildings. Both should be linked, as design principles can help with a better life cycle approach and vice versa and used in public procurement and the EU sustainable finance framework (see 2.3 and 2.4).

2.3 Develop and align circular international public procurement

The majority of assignments in infrastructure comes from public entities. Procurement can therefore be an instrument for positive, systemic change by promoting circularity. Various actions can be taken by all stakeholders involved to make circular tendering the norm:

- Make and promote the use of a standard international tendering method, a type of framework with common protocols, norms and standards that procurers can use and customize.
- Give the market the same perspective for what's to come. By aligning procurement, countries can give predictability and uniformity to the market, which is important for long term investments in innovation.
- Promote initiatives where governments act as an innovation facilitator: launching customers, pre-commercial procurement, innovation partnerships as a procurement form.
- Focus on Total Cost of Ownership (TCO) instead of initial investment costs when it comes to the price criteria in procurement (see also 2.4).
- Use common sustainability assessment tools and circular indicators applicable for both buildings and infrastructure.

Specific coalitions (see above) could be set up for procurement, such as the existing Big Buyers Group 'Circular construction - roads, infrastructure, public space'; they can work out and apply the same strategies on an international level. These groups can be a means to build upon existing good practices, where frontrunners can share knowledge and others can learn and build upon this.

2.4 Use public funds and financing to support and accelerate circularity in infrastructure

Structural financial change is needed to make the transition to circular infrastructure, as this requires significant (public) investments. In the EU this can be done via various pathways, either by financing in a way that promotes circularity, giving out subsidy grants and correctly assessing the price of a project.

Part of the funds in the Recovery Plan for Europe has to be spent on sustainable investments. Furthermore, various financial actors provide sustainable funds. The question is: what projects should be considered as sustainable?

The Taxonomy is the EU initiative to define this and create a common language for sustainability. It sets performance thresholds that help to identify environmentally friendly activities. If the thresholds are set high enough, the Taxonomy could be an important instrument to promote circularity.

It is relevant to take into account what percentage of secondary materials should be in an infrastructure work to be eligible for sustainable funding. This should be high enough to award only the “best in class”, so that it can really drive circularity.

European research funds, such as Horizon Europe, currently offer opportunities to support circularity in the construction sector and have the potential to support circularity in infrastructure as well. It is relevant to seek synergy with calls related to the built environment, digitalisation and the new industrial strategy.

The Trans-European Transport Network (TEN-T) includes infrastructure within its scope. This could offer opportunities to drive circular developments, linked to maintenance, digitalisation and standardization.

Stimulate using TCO instead of focus on Capex

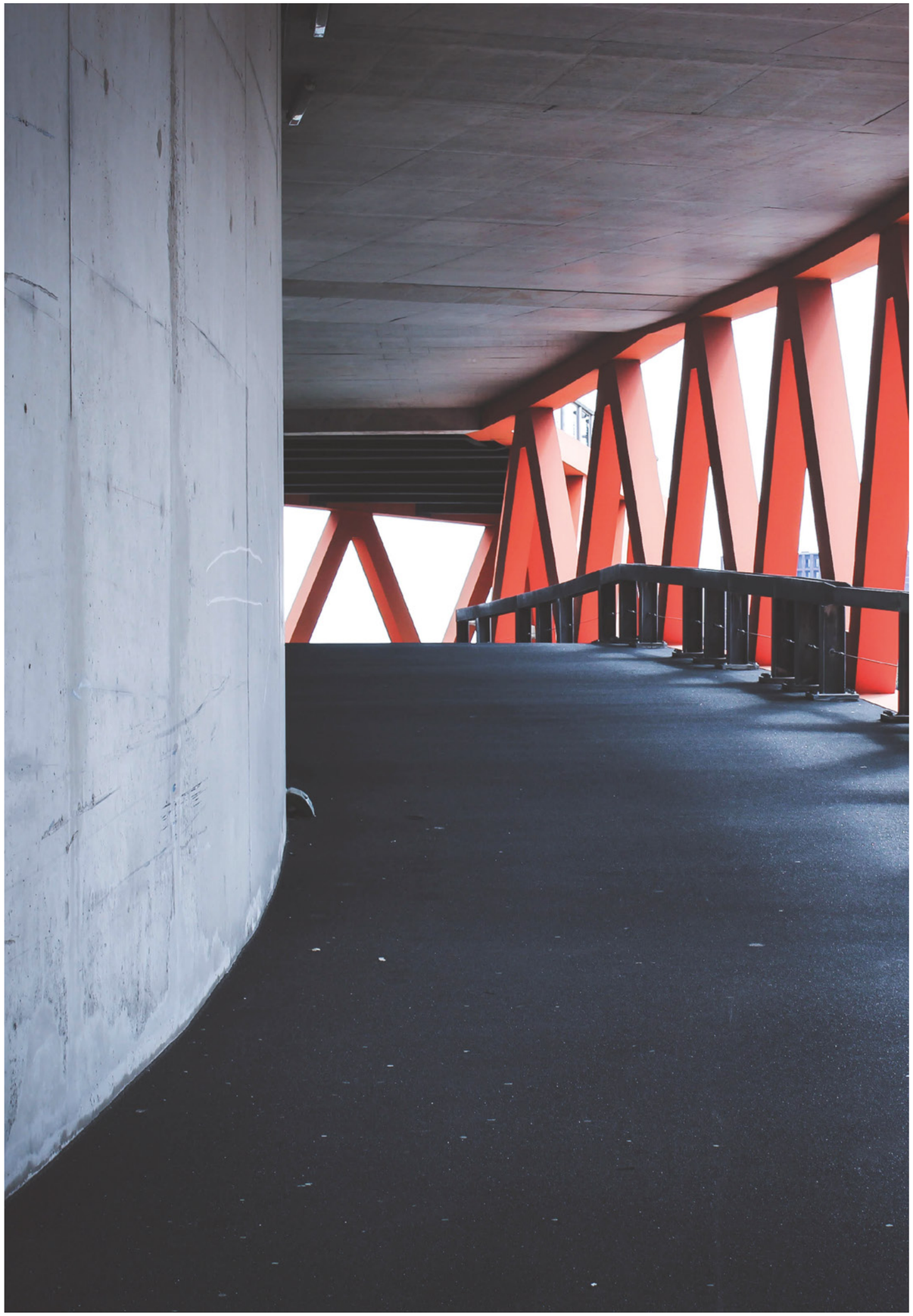
In general, businesses and financiers focus mainly on capital expenditures (capex) when looking for and judging funding and financing projects. This is usually less favourable for circular projects. A total cost of ownership approach, where all phases of the project are included (e.g., also end-of-life decommissioning), could prove the key to get more circular infrastructure projects funded and to get more focus on life extension and renovation projects, instead of focusing on new constructions.

The OECD is working on this, and the European Investment Bank, World Bank and other public and private financiers could incorporate a set of criteria to boost circularity. This could also be taken into account when implementing certain policy programs or when setting up (price) criteria for public procurement.

3. Closing remarks: what’s next?

To work on these actions, we can start now, drawing on existing knowledge, best practices and lessons learned about how to make infrastructure circular and climate neutral. The Netherlands is happy to share and is looking for European and international partners who have the same vision and ambition and who want to work together to unlock the potential of circular infrastructure. We look forward to engaging with the world to make that happen!

Want to work together with us on this? Be sure to send your ideas, thoughts and proposal(s) to circulair@rws.nl.



Links and URLs

Order of links is as they appear in the document.

- Ladder of Circularity (10-R): https://www.pbl.nl/sites/default/files/downloads/pbl-2018-circular-economy-what-we-want-to-know-and-can-measure-3217.pdf
- Circular procurement: https://www.copper8.com/wp-content/uploads/2018/10/Circular-Procurement-in-8-steps-Ebook.pdf
- Van Hattum en Blankevoort (vHeB): https://www.vhbinfra.nl/
- CB'23 Platform: https://platformcb23.nl/
- Climate Neutral and Circular Infrastructure: https://www.rijksoverheid.nl/documenten/rapporten/2020/06/15/bijlage-1-strategie-naar-klimaatneutrale-en-circulaire-rijksinfraprojecten
- A Circular Economy in the Netherlands by 2050: https://www.government.nl/documents/policy-notes/2016/09/14/a-circular-economy-in-the-netherlands-by-2050
- Circular Construction Economy: https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Circular-Construction-Economy.pdf
- Work Program on Monitoring and Evaluation Circular Economy 2019–2023: https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Circular-Economy-Implementation-Programme-2019-2023.pdf
- bi-annual monitoring report, ICER: https://www.pbl.nl/sites/default/files/downloads/2021-pbl-icer2021_english_summary-4228.pdf
- Climate Neutral and Circular Infrastructure: https://www.rijksoverheid.nl/documenten/rapporten/2020/06/15/bijlage-1-strategie-naar-klimaatneutrale-en-circulaire-rijksinfraprojecten
- environmental cost indicator (ECI): https://milieudatabase.nl/wp-content/uploads/2020/09/Guide_to_environmental_performance_calculations_July_2020.pdf
- DuboCalc: https://www.dubocalc.nl/en/
- the Dutch National Environmental Database Foundation: https://milieudatabase.nl/an-introduction-to-the-nmd/
- Buyer groups for sustainability | PIANOo - Dutch Public Procurement Expertise Centre: https://www.pianoo.nl/en/sustainable-public-procurement/buyer-groups-sustainability
- Bouwcirculair: https://bouwcirculair.nl/
- Circular Procurement in 8 Steps: https://www.copper8.com/wp-content/uploads/2018/10/Circular-Procurement-in-8-steps-Ebook.pdf
- Copper8: https://www.copper8.com/en/
- the database circular road furniture: https://rwsinnoveert.nl/publish/pages/191173/launching_customer_a4_liggend_opmaak_v12.pdf
- CB'23 Platform: https://platformcb23.nl/
- Measuring circularity in the construction sector: https://platformcb23.nl/images/downloads/Platform_CB23_Guide_Measuring_circularity_2.0.pdf
- Circular Buildings - a measurement methodology for detachability v2.0: https://www.dgbc.nl/nieuws/circular-buildings-een-meetmethodiek-voor-losmaakbaarheid-v20-nu-online-6126
- guideline on circular design: https://platformcb23.nl/images/leidraden/PlatformCB23_Leidraad_Circulair-Ontwerpen_versie1.pdf
- Inspiration book on circular design in the infra: https://ipvdelft.nl/inspiratieboek-circulair-ontwerpen/
- circular objects: https://puc.overheid.nl/rijkswaterstaat/doc/PUC_166614_31/
- movie 1: https://www.youtube.com/watch?v=K-0cnX5feFY
- movie 2: https://www.youtube.com/watch?v=wtY4_QXcVsM
- Meerdink Bridges: https://www.meerdinkbruggen.nl/tag/bridge/
- Arc2 architects: https://www.arc2.nl/
- Circular Infrastructure Business Models, Insights from the Open Learning Environment Circular Bridges and Viaducts: https://pacecircular.org/sites/default/files/2020-01/20-01-2020%20Circular%20infrastructure%20business%20models%20report.pdf
- Platform for Accelerating the Circular Economy (PACE): https://pacecircular.org/
- passports in the construction sector: https://platformcb23.nl/images/downloads/Platform_CB23_Guide_Passports_for_the_construction_sector_2.0.pdf
- Madaster: https://madaster.com/
- materials expedition 1: https://www.bouwendnederland.nl/media/7857/lessons-learned-materialen-expeditie-def_september_2020.pdf
- Nationale Bruggenbank (National Bridges Bank): https://www.nationalebruggenbank.nl/
- reuse of bridges: https://www.nationalebruggenbank.nl/wp-content/uploads/2021/03/20607-RWS-AMROR-handleiding-bruggen-16PS.pdf
- CIRCO: https://www.circonl.nl/circo-tracks-in-seven-steps-from-linear-to-circular/
- Lexicon Circular Construction: https://platformcb23.nl/images/downloads/PlatformCB23_Lexicon_Circular_Construction_2.0.pdf
- measuring circularity in the construction sector: https://platformcb23.nl/images/downloads/Platform_CB23_Guide_Measuring_circularity_2.0.pdf
- passports for the construction sector: https://platformcb23.nl/images/downloads/Platform_CB23_Guide_Passports_for_the_construction_sector_2.0.pdf
- roadmap circular procurement: https://mraduurzaam.nl/circulair/circulair-inkopen-opdrachtgeverschap/roadmap-circular-procurement-commissioning/
- Building As Material Banks (BAMB2020): https://www.bamb2020.eu/
- Big Buyers Initiative: https://bigbuyers.eu/
- Circular & Fair ICT Pact: https://circularandfairictpact.com/
- European Committee for Standardization: https://www.cencenelec.eu/
- Big Buyers Group 'Circular construction - roads, infrastructure, public space: https://bigbuyers.eu/working-groups/circular-construction

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Colophon

This publication is the result of a collaboration between Rijkswaterstaat (RWS), Holland Circular Hotspot (HCH), The Transition Team Circular Construction Economy, Rebel Group, and The Netherlands Organisation for Applied Scientific Research (TNO).

The foundations would like to thank all contributors, editors, reviewers, best practice providers, and any individual or organization that took part in the production of this document.

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January 2022

Cover image: Hovering, ipv Delft