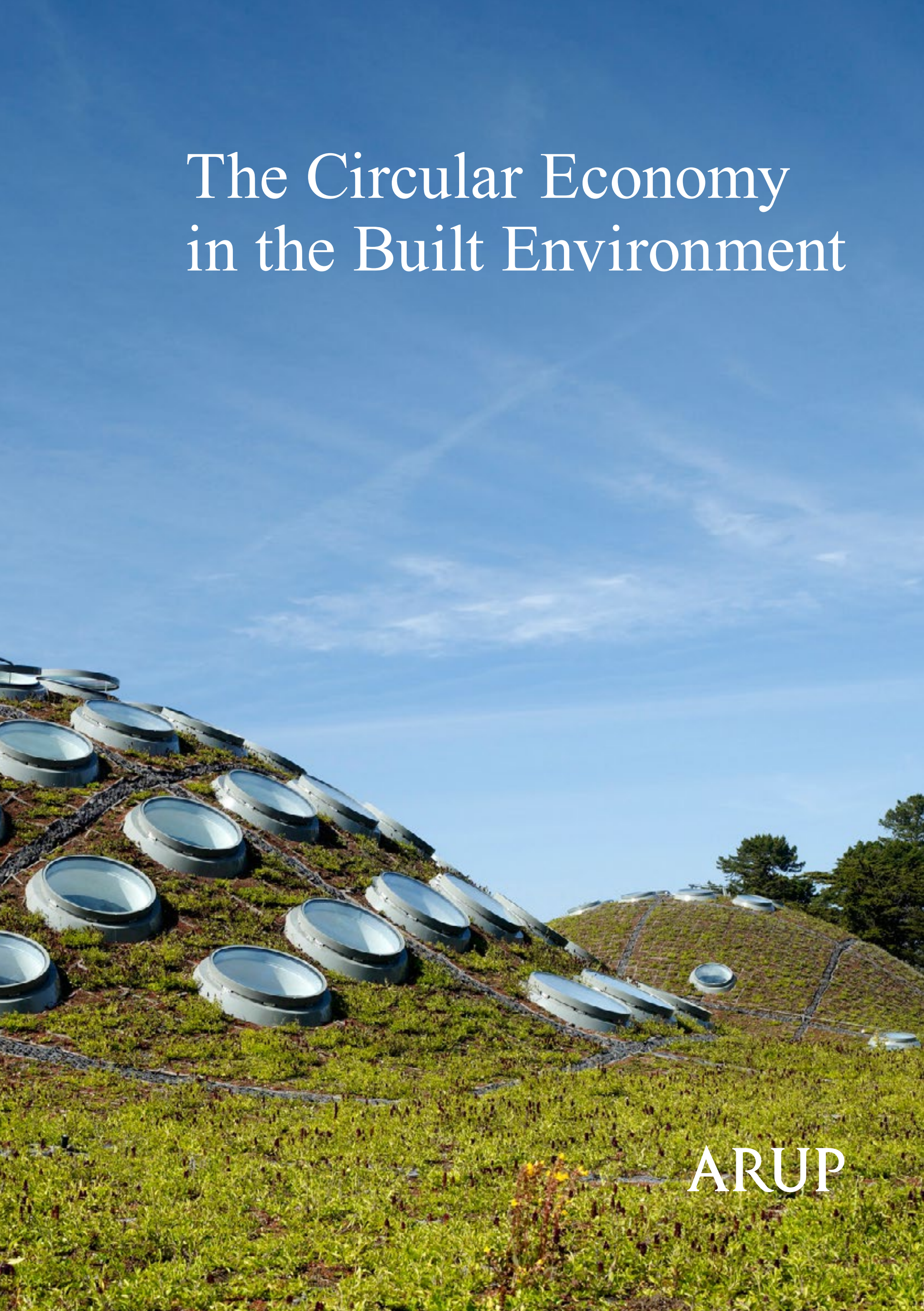
The Circular Economy in the Built Environment



ARUP

About Arup

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services. From 90 offices in 38 countries our 12,000 employees deliver innovative projects across the world with creativity and passion.

Arup Foresight + Research + Innovation

Foresight + Research + Innovation is Arup's internal think-tank and consultancy which focuses on the future of the built environment and society at large. We help organisations understand trends, explore new ideas, and radically rethink the future of their businesses. We developed the concept of 'foresight by design', which uses innovative design tools and techniques in order to bring new ideas to life, and to engage all stakeholders in meaningful conversations about change.

Contacts

Carol Lemmens
Director and Global Business Leader
Management Consulting
Carol.Lemmens@arup.com

Chris Luebkeman
Arup Fellow and Director
Global Foresight + Research + Innovation
chris.luebkeman@arup.com

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ARUP

13 Fitzroy Street
London W1T 4BQ
arup.com
driversofchange.com

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Cover: California Academy of Sciences, San Francisco, USA


Bohemia
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Foreword

"Moving towards a truly circular economy will not be achieved in one step. However, this report represents tangible progress on the journey towards a more sustainable, efficient, and resilient future. Arup is in this for the long haul, because, even if it takes a generational shift to get there, the direction of travel represents a far better future for our shared society."
—Gregory Hodkinson, Global Chairman, Arup

It is clear that the journey towards a truly circular economy will take many years, if not decades. It is also clear, to Arup at least, that this is a journey society must make together if it is to make vital reductions in resource use, waste and carbon.

This report explores the meaning and application of the circular economy within the built environment. It is intended to raise awareness of the circular approach, and to identify the many challenges, enablers and opportunities available to Arup and others in making the circular economy a reality across the built environment.

As things stand, the application of the circular economy to our sector is less than straight forward. Existing frameworks eloquently express principles and philosophies. But they fail to offer specifics on how built environment assets and services must be developed, procured, designed, constructed, operated, maintained and repurposed.

The systemic nature of the circular economy requires both the ecosystem and its individual components to change. This means that governance, regulation and business models could potentially be even more important to achieving the transition than design and engineering.

To get there, a dedicated built environment roadmap or framework is needed, together with a set of guiding principles for the design, engineering and construction sector. This will need to focus both on the economic business case and the opportunities to develop new ways to design and deliver projects. Such a framework would also help to drive innovation opportunities across the industry.

At Arup, we have committed ourselves to achieving the following five actions:

1	To define effective circular economy design principles for our industry
2	To co-develop and share research that can challenge our industry to apply circular economy principles
3	To develop projects and enable prototyping with our partners
4	To help educate our sector through learning programmes
5	To work with others to articulate the shared values and mutual gains relevant to academia, government, corporations and individuals

As a global Knowledge Partner of the Ellen MacArthur Foundation, Arup is actively building relationships with other organisations from across the Circular Economy 100 (CE100) network. Partnership is a vital part of the journey we are on, and we look forward to finding new opportunities to collaboratively integrate circular economy principles into the built environment.

Left: New National Library, Singapore: sunshades prevent direct sunlight from entering the building during the middle of the day

Introduction

The €1.8tn opportunity revealed by the Ellen MacArthur Foundation reaffirms the economic rationale of moving towards a circular economy. Realising and capturing the benefits of this systemic transition requires a cross-industry, cross-performance, and multidisciplinary approach.
—Ellen MacArthur Foundation, 2016

Decoupling economic growth from finite resource consumption

Consumption and use of natural resources has generally followed a linear approach. Materials are sourced, used and finally disposed of as waste. Known as the take-make-use-dispose model, this produces negative externalities that include rising carbon emissions, increased pressures on landfill, unsustainable levels of water extraction and widespread ecosystem pollution.

An abundance of cheap natural resources has enabled this approach to endure. However, as the world's population grows and resources become harder and more expensive to access, it is becoming ever more critical to find alternative means of sourcing and using materials.

The built environment sector is a major consumer of natural resources. It recognises the need to fundamentally evolve the processes, components and systems it utilises to obviate waste and increase efficiency. There is an incredible breadth of opportunity that this will create across the entire supply chain. Some manufacturers, for example, are already designing products that can be reused or repurposed. Arrangements to incentivise the return of products are starting to emerge. But there is as yet no clear articulation of exactly how individual companies and processes will need to change across the industry. The impetus required to catalyse this shift

Left: Metropol Parasol, Plaza de la Encarnación, Seville, Spain: a network of timber beams forming one of the largest timber structures ever built

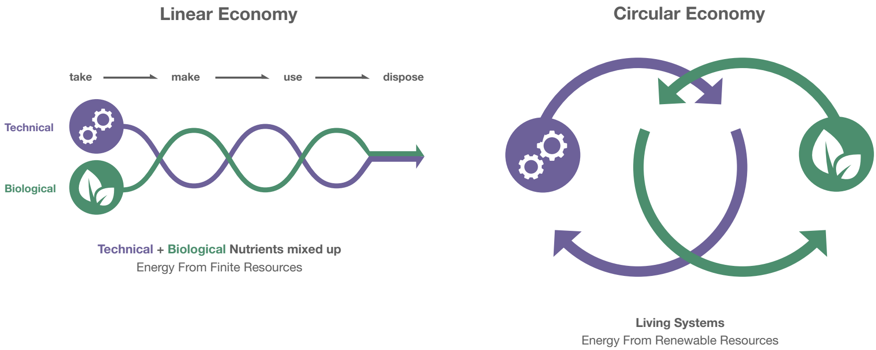


Figure 1: Adapted from Ellen MacArthur Foundation, 2015

has not yet materialised. The structure of the industry also hinders transformative change.

The circular economy concept offers a chance to make the step change needed. It aims to decouple economic growth from resource consumption. Instead, products and assets are designed and built to be more durable, and to be repaired, refurbished, reused and disassembled. This maintains components and their materials at the highest useful purpose as long as feasible which minimises resource waste.

By moving away from the linear model to an ecosystem where natural capital is preserved and enhanced, renewable resources are optimised, waste is prevented and negative externalities are designed out. Instead, materials, products and components are held in repetitive loops, maintaining them at their highest possible intrinsic value.

As things stand, a global economy predicated on growth is helping to increase the world's middle class and its purchasing power. This trend is starkly at odds with the finite nature of our natural resources. Ongoing volatility in global commodity markets shows we need to reconsider how society consumes goods.

Gradual change is underway. We are already seeing the emergence of a sharing economy. Research suggests that young people are more inclined to rent, lease or share items such as clothes, cars or houses than previous generations. These

Inside Cities exhibition, Arup Phase 2

nascent patterns have spread from the fast-moving consumer goods industry to other areas, including the built environment. This could mean that fewer resources are needed, assets are used more fully and their lifecycles are extended and diversified.

Minimising negative externalities

The built environment comprises the man-made elements of our surroundings such as buildings as well as infrastructure including transportation, telecommunications, energy, water and waste systems. Design, planning, and construction contribute to the quality of the built environment, which has a significant impact on human health, well being and productivity.

Minimising negative externalities is a core aim of the circular economy. In the built environment these include climate change, water, soil, noise and air pollution. They also include less tangible impacts on human and animal welfare, health, employment and social equality.

These externalities can apply to both the operation of assets and the sourcing, manufacture, transportation, installation of materials and components, and disassembly. Preventing or minimising these impacts is critical to enhancing natural capital and maximising the use and value of resources. Measures to quantify the cost of negative

Minimising negative externalities such as GHG emissions, noise and air pollution is a core aim of the circular economy

externalities and the value of ecosystems services play an increasingly important role in this process.

Why is Arup interested in the circular economy? As an independent firm of designers, planners, engineers, consultants and technical specialists, Arup believes that the approach offers a way to help shape a better world. This report uses the Ellen MacArthur Foundation's ReSOLVE framework (see page 19) to outline key principles of the circular economy and explore practical applications that can benefit all parties working in the built environment sector.

The case studies included in this report provide practical examples of how each element of the ReSOLVE framework can be applied, together with the benefits these can deliver. However, while there are many projects already employing circular economy principles, few have resulted in zero waste or have demonstrated very high, sustained levels of reuse. Although the examples here are not all entirely circular, we believe they represent important stepping stones that could be expanded, integrated and scaled up.

To visualise how this could happen, an outline of how the circular economy would function for a commercial building (see page 44) has been developed. The concept shows stakeholders their role and the benefits available to them; this will be developed and tested with partners in the months to come. Plans to expand this model for use with infrastructure

Bosco Verticale, Milan, Italy: two residential towers incorporate 900 trees, 5,000 shrubs and 11,000 plants

are also underway.

To complement the building illustration, a matrix and diagram, mapping the Ellen MacArthur Foundation ReSOLVE framework to an adapted version of Stuart Brand's 'Layers' diagram (System, Site, Structure, Skin, Services, Space, Stuff) has also been developed — see pages 64-67. The System level has been added to expand the concept to cover more of the built environment than just buildings. The matrix demonstrates how the components, materials, systems and services in the built environment would function within the context of different lifespans.

The Built Environment: from Linear to Circular

"Adopting circular economy principles could significantly enhance global construction industry productivity, saving at least US$100bn a year."
—World Economic Forum, 2016

The built environment in the context of the circular economy

The engineering and construction industry is the world's largest consumer of raw materials. It accounts for 50% of global steel production and consumes more than 3bn tonnes of raw materials.[1]

Global demographic and lifestyle changes are increasing the demand for these resources, many of which are becoming scarcer and harder to extract. Natural resources are currently being consumed at twice the rate they are produced. By 2050, this could be three times. Growth in the world's population and, in particular, its middle classes (which will expand from two to five billion by 2030, adding to existing demand for homes and services) is putting unprecedented pressure on natural resources.[2] Competition for resources and disruptions to supply are already contributing to volatile materials prices, creating uncertainty in the short term and increasing costs overall.

Stricter global environmental regulations aimed at protecting fragile ecosystems are also making it harder and more costly to extract and use certain resources. The built environment is under increasing pressure to minimise its impact. A circular approach could help the sector to reduce its environmental footprint, and to avoid rising costs, delays, and other consequences of volatile commodity markets.

Materials and waste in the UK construction industry

The construction industry in the UK consumes more than 400m tonnes of materials every year, making it the nation's largest consumer of natural resources

Adding demolition, the sector is also the largest contributor of waste, contributing more than 30% of global annual greenhouse gas emissions and consuming up to 40% of all energy

Waste management and disposal costs are huge, swallowing up 30% of construction firms' pre-tax profits.

Given the potential to save £60bn in primary resources by 2030 in the European Union,[3] and to add £3-5bn to London's GDP by 2036,[4] there are clear advantages to adopting circular economy practices across the sector. This would involve reshaping the way projects are procured, designed, constructed, operated and repurposed.

The following section addresses how circular economy practices might function in the built environment and the benefits that these could bring throughout the value chain.

Origins of circular economy thinking

The circular economy model has its roots in concepts dating back to the 1970s, including the Club of Rome's 'Limits to Growth' theory, Braungart and McDonough's 'cradle to cradle' concept, Stahel's 'performance economy', and Lyle's 'regenerative design' model, to name a few.

The approach has gained attention recently thanks to the Ellen MacArthur Foundation, a charity dedicated to promoting the global transition to the circular economy. Drawing on these earlier works, the Foundation developed the system or 'butterfly' diagram (Figure 2) based on the notion that material flows can be divided into two interacting loops: the technical and biological resource cycles.

Within the biological cycle, renewable and plant-based resources are used, regenerated and safely returned to the biosphere — as in composting or anaerobic digestion. The bio-economy is a growing sector with the potential to lower raw materials consumption, reduce waste and generate higher-value products for sustainable biological re-use.

Within the technical cycle, man-made products are designed so that at the end of their service life – when they can no longer be repaired and reused for their original purpose their components are extracted and reused, or remanufactured into new products. This avoids sending waste to landfill and creates a closed-loop cycle.

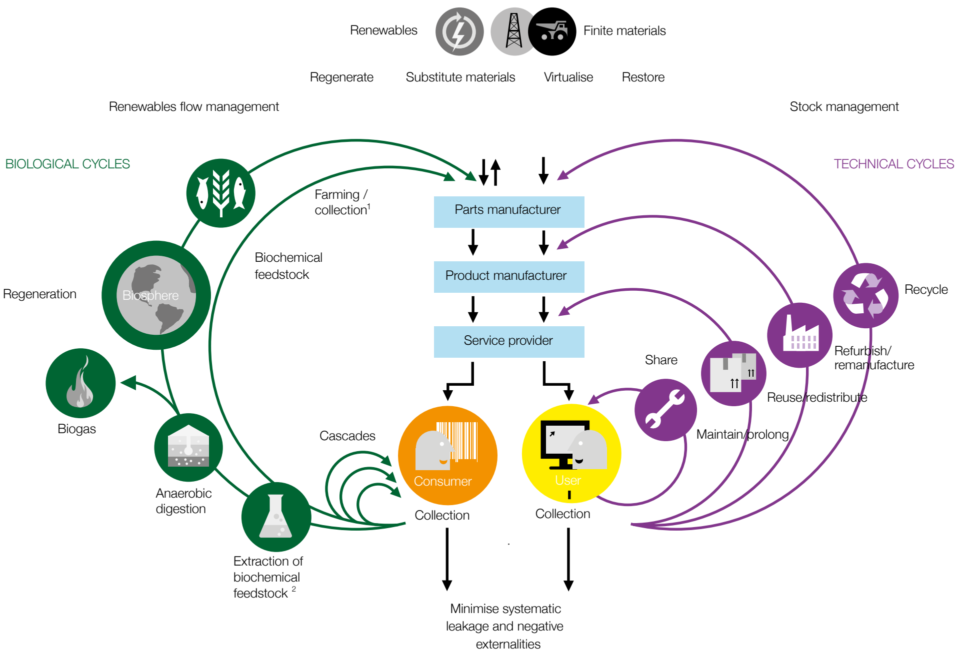


Figure 2: Adapted from: Ellen MacArthur Foundation and McKinsey Center for Business and Environment; Adapted from Braungart & McDonough, Cradle t Cradle (C2C).

1. Hunting and fishing 2. Can take both post-harvest and post consumer waste as input

Dartington Primary School, UK: reclaimed tyres act as planters in the school grounds

The ReSOLVE framework

The ReSOLVE framework is a key output of the Ellen MacArthur Foundation's research. It outlines six actions to guide the transition towards a circular economy:

1. Regenerate
2. Share
3. Optimise
4. Loop
5. Virtualise
6. Exchange

The six elements can be applied to products, buildings, neighbourhoods, cities, regions, or even to entire economies.

In this section of the report, the framework is used to illustrate how the circular economy can be applied in the built environment. Following a description of the six ReSOLVE actions, a range of case studies are included to illustrate practical examples. The projects and initiatives chosen each contain elements of the ReSOLVE framework. A summary of how these compare can be found in the Appendix.

It is worth noting that while these projects exemplify elements of circularity, few of them are perfectly circular. As discussed in Section 4, a truly circular economy will not be achieved until different scales – including assets,

Regenerate	Regenerating and restoring natural capital	Safeguarding, restoring and increasing the resilience of ecosystems Returning valuable biological nutrients safely to the biosphere
Share	Maximising asset utilisation	Pooling the usage of assets Reusing assets
Optimise	Optimising system performance	Prolonging an asset's life Decreasing resource usage Implementing reverse logistics
Loop	Keeping products and materials in cycles, prioritising inner loops	Remanufacturing and refurbishing products and components Recycling materials
Virtualise	Displacing resource use with virtual use	Replacing physical products and services with virtual services Replacing physical with virtual locations Delivering services remotely
Exchange	Selecting resources and technology wisely	Replacing with renewable energy and material sources Using alternative material inputs Replacing traditional solutions with advanced technology Replacing product-centric delivery models with new service-centric ones

Figure 3: Adopted from: 'Growth Within: a circular economy vision for a competitive Europe', Ellen MacArthur Foundation, SUN, McKinsey Center for Business and Environment

Madrid + Natural tackling climate change through the greening of existing infrastructure to provide natural habitats for wildlife and spaces for human enjoyment

buildings, infrastructure, cities and regions – are integrated into an interdependent and cohesive whole. Instead, these case studies showcase the circular economy practices already in existence in the built environment; and describe how innovation and cross-sector collaboration could be scaled up and integrated to achieve a more complete circular economy.

3.1 Regenerate

Regenerating and restoring natural capital

In the built environment, regeneration allows for efficient and circular building performance by reducing negative externalities, consumption of primary resources and waste. This helps to safeguard, restore and increase the resilience of ecosystems.

Net zero strategies, for example, promote low-impact design, materials and operation of assets and buildings. This also helps to reduce the negative social, environmental and economic impacts of the built environment – including emissions, air pollution, waste and associated costs.

Biological resources can also be extracted and reused via anaerobic digestion, composting or bio-refining. This generates energy and cuts emissions. And allows more biological material to be returned to the soil to replenish it.

Diverting waste from landfill, using materials and products more efficiently, and improving air quality could also enhance the reputation of individual companies and the wider industry. At the same time it would make cities cleaner, more attractive and more liveable.

Safeguarding, restoring and increasing the resilience of ecosystems

Solutions that favour the sustainable use of materials and resources, avoid waste and negative externalities, and restore natural systems are regenerative by design.

In the built environment, resilience enables assets and services to be reliable, robust and adaptable to sudden shocks and ongoing stresses. Resilience can be enhanced by the choice of materials and design employed. Flexibility and

Bussum Water Tower, the Netherlands: one of the most sustainable office buildings in the Netherlands, the building includes its own wastewater and sewage treatment facility

redundancy can be factored in. And opportunities for future reuse and disassembly can be taken into account.

These considerations will help the industry to ensure assets are designed to withstand known and unknown future conditions. They will also help to lower the environmental impact of materials use and waste, and ensure assets are built for longer lifespans and evolving needs.

Processes that restore ecosystems and increase resilience are already being developed for the built environment. Arup's Madrid + Natural initiative proposed nature-based design solutions to regulate Madrid's urban environment. These included replicable green infrastructure solutions to tackle city challenges such as pollution, extreme heat events, water scarcity, flooding, loss of biodiversity, and reduced access to green spaces.

Employing an incremental approach, small-scale interventions were planned to connect with existing larger green spaces and natural systems across the city. Open spaces, parks, nature areas and buildings with green roofs and façades would be interconnected. Where the strategy has been implemented it has reduced temperatures by up to 4.5°C

Returning valuable biological nutrients safely to the biosphere

Regenerating also includes the return of biological nutrients to the biosphere through processes such as composting or anaerobic digestion. Closing these loops helps to ensure energy and nutrients, as well as bio-chemicals such as biogas, are recovered. Valuable by-products and other nutrients or products may also be generated, creating new markets and revenue streams.

As part of Scotland's Making Things Last: A Circular Economy Strategy, a team at Heriot-Watt University developed the Horizon Proteins method. This takes underused resources such as wheat, barley and yeast from the brewing and distillery industries to create protein products for fish and animal feed. The process – which recovers protein from whiskey production by-product pot ale – is a low-cost and low-energy solution that reduces imports and the associated environmental impacts and costs. It also provides the whiskey industry with an additional high-value revenue stream and supports the development of a new market for protein products such as salmon feed.

3.2 Share

Maximising asset utilisation

Optimising asset use can allow the built environment sector to use spaces, infrastructure and vehicles more efficiently. Peer-to-peer sharing is already well established in the car industry where schemes such as Zipcar, Getaround, BlaBlaCar, and Uber allow users to rent out or share vehicles, making more use of a smaller number of assets and reducing negative impacts such as traffic congestion and pollution. In the built environment, asset owners can rent out or share under-used spaces, building and construction materials, and equipment.

Co-location, shared and flexible working spaces are becoming increasingly common in densely populated cities. By occupying less space and minimising the time an asset is idle, fewer resources are needed to deliver the same function or service, and thus less waste is produced. This includes housing more people within a smaller footprint, making greater use of offices and workplaces throughout the 24-hour cycle, and sharing facilities and vehicles.

Car2Go, Amsterdam: car sharing schemes and clubs make greater use of a smaller number of vehicles, thereby reducing negative impacts such as traffic congestion and pollution

Shared ownership, sharing platforms and the 24-hour economy are enabling a shift in the way that space and services are used and accessed. The approach can also provide additional revenue and cost savings for owners and operators. For example, by introducing flexible working for 20% of its office space and 18,000 staff, the Lloyds Banking Group removed 1,000 desks from its London offices and saved £10m.

Co-living is also gaining popularity, with companies such as The Collective, WeLive, and Common providing low-cost homes with private bedroom spaces and flexible, communal kitchens, dining rooms and libraries, which can convert to bars, mailrooms and event spaces.

Airbnb is one of the best known examples of the asset optimisation business model. The site, which allows people to rent out spare rooms in their homes, now has over 60 million users; two million listings across 192 countries; and the company is valued at around US$25bn.[5] In 2014, a study found that in the US alone, Airbnb guests use 63% less energy than hotel guests. In Europe, in just one year Airbnb saved water equivalent to the contents of 1,110 Olympic-sized swimming pools, and avoided GHG emissions equivalent to 220,000 cars.[6]

Pooling the usage of assets

Sharing economy businesses often use online platforms or apps to collect and share real-time data, and to maximise

Wikihouse is the world's first open source house that anyone can download, digitally manufacture and assemble for themselves in days, with no construction skills

the use of assets. In the built environment, open-source design platforms such as WikiHouse allow designers to share designs with users so that they can customise or even construct buildings themselves.

The exchange of information — in a standardised format — facilitates the adoption of best practice. And this encourages the take-up of associated principles such as modular construction, design for disassembly, and the use of sustainable and circular materials. Community-driven modifications and improvements to designs and software can increase the lifespan of designs, maximise their use and support the standardisation of components across multiple applications.

Described as 'Airbnb for off-site meeting spaces', HeadBox allows users to rent under-used spaces for meetings, team away-days, private parties, conferences and workshops. An easy-to-use online platform helps the service reach a wide audience. At the same time it cuts costs for conventional event space booking agents and makes it simpler for asset owners to take advantage of under-used space.

3D Hubs is an online service platform that allows designers and engineers to access underutilised 3D printer capacity in their city. The site now includes over 32,000 printers in over 150 countries.

Reusing assets
Reusing materials and components through resale or redistribution can create economic as well as social and environmental benefits. Sharing built environment services can also stimulate greater collaboration between asset owners and operators, technology companies, platform developers and other industry partners. These collaborations can lead to technical innovation, cut costs, reduce resource use and increase trust amongst users.

Collaboration is already common in parts of the built environment sector. But connecting more disparate elements of the supply chain through mutually beneficial partnerships is essential to scaling up circular economy practices and creating value for all.

Globechain is a reuse platform that matches businesses, charities and individuals who want to acquire or give away unwanted or surplus stock and equipment in the construction, retail and office sectors. This supports new supply chains for secondary materials and encourages reuse.

By gathering and analysing data, the company also evaluates the social, economic and environmental impacts of the exchanges. This enables businesses to assess and report on the effects of reusing, upcycling and recycling items.

Telefonica used Globechain to pass on unwanted office furniture to the charity Growing Networks. In doing so it saved around £3,000 in landfill charges and skip hire costs. The charity also saved between £3,000 and £4,000 on the cost of new furniture.

Reuse platforms for unwanted or surplus equipment encourages reuse

3.3 Optimise

Optimising system performance
Optimised assets, products and systems are those which operate at maximum efficiency and performance. So how can optimisation be achieved in the built environment? The key is maintaining materials and components at their highest value whilst employing design and construction processes to maximise efficiency, eliminate waste, and promote reuse and repurposing.

Exterior of the White Collar Factory

Digital technologies and flexible design methodologies help to optimise the performance of assets, whilst off-site construction and modular components reduce waste produced on-site. To eliminate primary material use, components and materials may also be reused to construct new buildings, repurposed for use in infrastructure or transferred for use in other sectors.

Prolonging an asset's life

Designing for longevity ensures the long-term durability, utilisation and value of assets. Durable materials and robust construction standards can reduce maintenance costs and extend the economic viability of a building or structure. Standardised components manufactured off-site to higher quality control standards can minimise the risk of structural faults and reduce long-term maintenance requirements.

Designing for longer lifespans also reduces waste and helps ensure assets are used optimally throughout their lifecycles. Furthermore, by designing flexible building cores, developers can enable assets to switch use at a later date – from commercial to residential, for example.

Arup collaborated on the implementation of sustainable solutions for Derwent London's White Collar Factory in Old Street, London, with architects Allford Hall Monaghan Morris. It contains commercial, residential and public spaces, and has been designed using exposed services, and adaptable

Left: Derwent's White Collar Factory in Old Street, London floor plates and internal fittings to allow for easy subdivision, interactivity and flexibility over time. These elements also facilitate the prolonging of the building's lifespan.

Integrated smart services including concrete core cooling, passive systems that maximise natural daylighting and ventilation, and power and data systems in raised access floors also help with repairs, maintenance and longevity. Durable materials were chosen for their low-carbon attributes and an innovative tablet-friendly building management system enables occupants to see how the building is performing, and to alter its settings to improve comfort levels.

White Collar Factory is designed to achieve occupational carbon emissions that are 25% lower than building standard Part L and offer a 10-33% reduction in operational energy costs per annum (depending on tenant fit-out). It is designed to meet both BREEAM Excellent and LEED Platinum requirements.

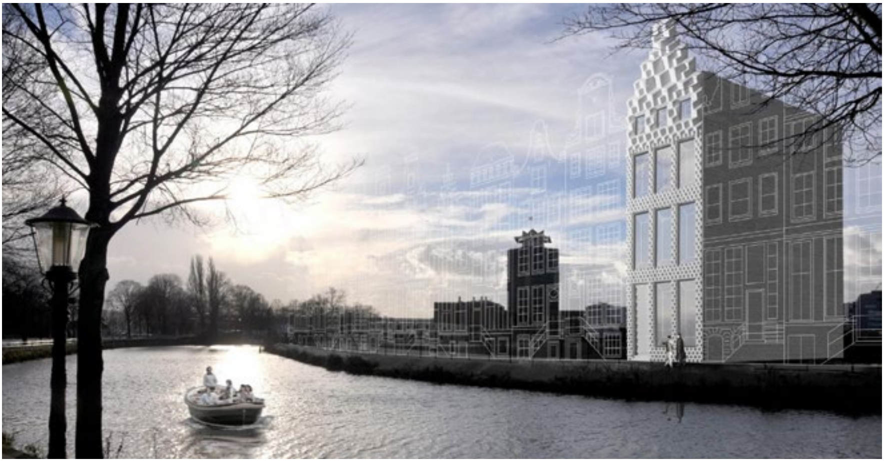
Decreasing resource usage

In the built environment, principles such as off-site construction and modular components reduce the amount of waste produced on-site and enable reuse and repurposing. Components and materials can then be reused for the construction of new buildings, repurposed for application in infrastructure or transferred for use in other industrial sectors — eliminating primary material use.

Waste can also be designed out from the start. Aligning design, construction, demolition and waste management enables circular resource and material flows between industries, sites and assets. Additive manufacturing technology, also known as 3D printing, can also reduce material use when manufacturing bespoke building elements.

In Amsterdam, a global team of architects, technology providers and engineers is working to design and build a full-sized 3D Print Canal House. Each building element is printed and tested at a 1:20 scale before the final printing, saving time and waste on later adjustments.

The house is designed around the concept of 'research and design by doing', enabling the public to test and feedback into the design. While the first floors and façades are



3D Print Canal House, Amsterdam: 3D printing technology can reduce waste, promote material resource efficiency and minimise transport needs

currently printed from polypropylene, the designers plan to eventually use bioplastics and plastic recycled on-site.

Arup is providing environmental impact assessment and rail engineering support to develop design strategies that reduce waste, promote material resource efficiency and minimise project costs. In collaboration with HS2 Ltd, Arup initiated a series of collaborative designing out waste (DoW) workshops. These involved a cross-section of HS2 Ltd team members – including the technical directorate, designers, rail system specialists, environmental consultants, architects and construction contractors.

The workshops identified cost savings of approximately £30m from reducing the 10 most common materials by 1%. Reusing excavated material resulted in cost savings of between £1.2 and £1.8bn.

Implementing reverse logistics

Reverse logistics is a closed loop approach that uses remanufacturing, refurbishment, repair, reuse or recycling to recover and process materials and products after the point of consumption. Incentivised return policies help to drive the flow of materials and products through the supply chain. Telecommunications companies, for example, often lease phones to customers to ensure they are returned.

Machinery manufacturer Caterpillar uses a deposit-return system to ensure used engine cores are returned. These are

DHL’s reverse logistics system uses the company’s logistics fleet to recover, track and redistribute waste and used materials

then remanufactured and resold (see 3.4 Loop). Collaboration between supply chain stakeholders helps to consolidate materials and create the scale needed to build a reverse logistics supply chain.

DHL’s reverse logistics system uses the company’s vast logistics fleet to recover, track and redistribute waste and used materials as part of the same delivery schedule. This can include anything from aluminium cans to clothing or furniture.

Between 2008 and 2014, the programme helped DHL lower carbon emissions from transport by more than 25% per million cases delivered.[7] Further optimisation is underway and the company now offers services such as on-site de-installation of finished goods, sorting, verification and management of returned materials streams.

DHL also partners with reuse and recycling operations to streamline the return of usable materials to the economy. The efficiency of the company’s data tracking network enables it to maximise the value of returned materials streams and plan ahead based on a known inventory.

3.4 Loop

Keeping products and materials in cycles, prioritising inner loops

Looping of materials and components takes place in both the nutrient and technical cycles, creating new uses for materials through remanufacturing and recycling. These include remanufacturing and recycling of machinery and equipment. Regular maintenance, refurbishment and repair help to maintain assets and products at their maximum utility.

Focusing on disassembly during the design phase increases the chance of effective second use and reuse pathways for components and materials. It also enables greater integration of recycled materials and components from other industries. Monitoring and tracking the performance of assets is also critical to enable looping opportunities further down the line.

Remanufacturing and refurbishing products and components

In the built environment, maximising the use of repurposed materials, components and structures supports their circulation within the industry and minimises the need for virgin materials. Remanufacturing keeps materials, components and even structures in use for longer, helping to reduce or lower waste. Integrating different construction and demolition sites and other industries enables materials and structures to be transformed or repurposed. Coupled with modularity, disassembly allows for the structure to be changed easily and reduces construction waste.

Caterpillar has been remanufacturing parts since the 1970s. The company is a world leader in reducing, reusing, recycling, and reclaiming materials. At the end of their lives it returns products to same-as-new condition and quality for a fraction of the cost of producing new ones.

This model has significantly reduced Caterpillar's costs for its own operations (especially labour costs) and those of its customers, as well as the quantity of materials it uses and the environmental impacts associated with its mechanical processes. Over the last decade, Caterpillar's

Caterpillar is a world leader in reducing, reusing, recycling and reclaiming materials

Arup helped Tata Steel by identifying the economic and environmental benefits that can be derived from reusing steel as opposed to recycling it

remanufacturing facilities have salvaged over 500,000 tonnes of materials. Caterpillar calculates that the remanufacture of a cylinder head in one of its machines leads to a 61% reduction in greenhouse gases, a 93% reduction in water use, 86% reduction in energy use, 99% reduction in waste to landfill and 99% reduction in material use compared to making a new product.[8]

Recycling materials

Recovering and recycling valuable materials reduces resource use and minimises waste, and it can cut costs and earn revenues for stakeholders in the built environment.

Buildings and structures can be designed to allow component parts to be easily separated and recycled. Standardisation of components will also facilitate this process and increase recyclability. Designing for reuse has the potential to significantly reduce carbon emissions and mitigate fluctuating materials prices. In the shipping industry, for example, Maersk has created a cradle-to-cradle passport including an online database and inventory to help identify and recycle steel and other components.

Arup helped Tata Steel to understand the potential to design steel for reuse. We helped Tata to prepare for a future economy where resource depletion and legislation could significantly change the commercial market for the metal.

This study used a financial model to assess the potential value of steel reuse to building owners under different scenarios. The results proved that there are clear economic and environmental advantages to reusing rather than recycling steel.

We calculated embodied environmental impacts and resource use for both recycling and reuse of steel at the end of life of two buildings. This revealed potential savings of 6–27% for a warehouse, 9–43% for an office and 2–10% for a whole building. The study also found that a building client could benefit from significant savings on materials costs — up to 25% and 16% per tonne of steel compared to conventional construction.

3.5 Virtualise

Displacing resource use with virtual use

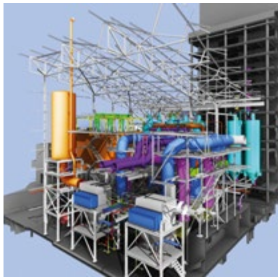
An ever-expanding number of apps and services have taken advantage of digital technologies to replace physical marketplaces. They match supply to demand virtually, making it easier to share and exchange goods and services, thereby saving time and money for users. Digital services can also facilitate real-time maintenance tasks that formerly required physical interventions, and their associated costs.

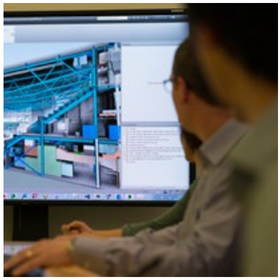
Virtual entertainment services such as Netflix are already replacing high-street rental shops like Blockbuster, just as Spotify and SoundCloud are replacing traditional music outlets. In the built environment, virtual marketplaces like Peerby and Streetbank connect users wanting to lend or borrow infrequently-used household items such as lawnmowers, tents, and drills.

Replacing physical products and services with virtual services

Building information modelling (BIM) is an innovative digital tool that communicates information relating to all phases of an asset's lifecycle. It can be used by stakeholders throughout the supply chain – including designers, contractors and building operators.

During the operation of a building, BIM collates data to facilitate monitoring processes, enable preventative





T. Park BIM collates data from the sludge treatment facility to enable preventative maintenance and to allow for better-informed upgrades and modifications

Virtual meeting rooms enable users to achieve the physical experience of a face-to-face meeting via a virtual platform

maintenance and allow for better-informed upgrades and modifications to systems and components.

The BIM process allows multiple stakeholders to collaborate more efficiently on the design, construction and operation of buildings. It also enables optimised design processes and supports the efficient performance and maintenance of buildings. By incorporating information on materials, BIM can help communicate any negative externalities as well as opportunities for recycling and remanufacture.

BIM was integral to the design of a state-of-the-art sewage sludge treatment facility devised by Arup in Hong Kong. 3D models were developed in the coordination, drawings production, operational and maintenance simulation as well as the material take-off for the design and construction of the facility. These enabled the facility to be viewed in virtual space, which in turn allowed stakeholders to examine clashes, operational access, delivery routes and extraction volumes for maintenance before construction commenced. The model crucially facilitated collaboration and coordination of the design, facilitating discussions between disciplines and enabling rapid resolution and visualisation of conflicts. The implementation of structured reviews reduced queries and clashes during construction on site.

Arup used building information modelling (BIM) software to develop a detailed 3D model of the facility that

Scotland’s Forth Replacement Crossing

not only helped design the plant in a resource-effective way, but also means the facility could potentially become a ‘material bank’ in the future. The 3D BIM model provides transparency about material composition in the facility. There is also potential to develop the 3D BIM model into an operation and maintenance tool to assist in prolonging the asset service life.

Replacing physical with virtual locations

Video conferencing and virtual meeting rooms enable users to achieve the physical experience of a face-to-face meeting via a virtual platform. Participants can share information, documents and presentations via platforms like Facetime and Skype, using PCs, laptops, smartphones or tablets. They can collaborate on projects in real-time and connect simply with colleagues around the world using real-time language translation. Services such as Mezzanine by Oblong provide a collaborative multi-wall platform for professional sharing and presenting.

Advances in virtual reality technology mean people will soon be able to interact in a computer-simulated office environment using an avatar. These technologies will allow virtual testing and optimisation of designs. They will provide better quality communications and enhance relationships between stakeholders. They will facilitate flexible working.

WikiHouse the construction of the world's first open source house in London, UK

And they will eventually reduce business travel and its environmental and financial impacts.

Delivering services remotely

Using embedded sensors and smart monitoring devices that anticipate problems and carry out maintenance works can extend the life of built environment assets. This creates efficiency gains, minimises waste and prolongs the life of assets. It also saves resources ordinarily spent on physical maintenance activities.

Arup challenged the proposed scheme to replace the over 50-year-old Forth Road Bridge, which spans the Firth of Forth in Scotland, with a bigger bridge. Eventually, it was decided to retain the old bridge for light traffic, and build a smaller and build a smaller new bridge, called the Forth Replacement Crossing. The consumption of a large amount of material resources was avoided by keeping the old bridge, which was essentially cascaded to a new form of use. At the same time, this resulted in significant project cost savings.

Open design and operating standards also allows components or systems to be easily exchanged or upgraded. Open standards increase compatibility and support the exchange of knowledge and information on systems performance. This also enables faster and more effective upgrades of built environment systems and components that can be shared using open virtual networks.

For some types of assets – such as commercial property — a rapid refresh of appearance, fit-out and structural components can increase use and minimise the need for structural changes. This requires a lifecycle approach to asset management and a focus on operational expenditure over capital expenditure.

Arup has collaborated with several partners to develop the WikiHouse concept, an open-source construction system that can be freely downloaded, customised and manufactured locally for assembly with minimal construction skills.[9] In 2014, the construction of WikiHouse 4.0 became the world's first open-source, digitally manufactured 2-storey house — part of the London Design Festival. The project, which was constructed in 12 days for under £50,000, features an open-source heat exchanger built from 3D printed parts and aluminium from repurposed drinks cans, modular timber components, and plug-and-play sensors and lights.

3.6 Exchange

Selecting resources and technology wisely

Sustainable energy and materials and advanced technologies that enable optimised, flexible, and user-focused design are slowly replacing static products and services and top-down design and operation approaches. Selecting these resources and mechanisms enables efficiency gains and minimises waste and other negative externalities. New business models such as leasing, performance-based models, and flexible use design also increase efficiencies. Digital technologies catalyse the pace at which new approaches are developed and adopted, helping stakeholders to collaborate and drive disruptive changes in how businesses are structured.

Replacing with renewable energy and material sources

For buildings this could mean generating energy and heat through closed-loop systems such as anaerobic digestion, or using wind, solar and other renewables as part of a low- and zero-carbon strategy.

Assets and buildings that adopt these strategies can also connect to the grid to feed in renewable energy. This would help to balance the grid, reduce the need for large centralised fossil fuel energy generation and increase the scope for efficient decentralised systems. These systems also contribute to lowering carbon emissions and the associated externalities created by burning fossil fuels, such as air pollution and other environmental costs.

The Arup designed Sky Believe in Better Building is a timber construction made using modular, prefabrication techniques. Constructed using a glue-laminated (glulam) timber frame and cross-laminated timber (CLT) floors, the building incorporates rooftop PV and connects to a site-wide biomass combined cooling, heating and power (CCHP) system. Thanks to the off-site methods, energy systems and materials selection, the building achieved BREEAM Excellent status and successfully met *passive*

Sky's Believe in Better Building, Osterly, West London

SolarLeaf's bio-reactive façade generates renewable energy from algal biomass and solar thermal heat

house standards.[10] The project was also taken from inception to site in just three months and delivered in under a year, contributing to substantial cost and carbon savings. In addition, it was designed for flexible use, with adaptable fittings and partitions that allow spaces to be easily altered for different functions.

Using alternative material inputs

Changing the way products and materials are selected, manufactured and used in the built environment can lower environmental impacts as well as costs. Biological nutrients and sustainable, renewable materials can replace materials that are heavily processed, and hard to reuse and recycle.

Resource management company Veolia is working on a project to upcycle sewage sludge into bio-plastic. It discovered that under certain conditions bacteria found in activated sludge and used in wastewater treatment processes can convert sewage sludge into valuable bio-polymers for the plastic and chemical industries. This closed loop initiative not only minimises waste, it also creates value for customers and partners.

Arup collaborated with designers The Living to produce the first mushroom brick tower, named Hy-Fi, in New York in 2014. The design was inspired by the mycelium product manufacturer Ecovative and uses bricks made from microscopic, fibrous fungi bound to agricultural waste to create a strong, resilient matrix that can be moulded into any shape. As it is made from agricultural waste and can by composted and returned to the earth easily at the end of its useful life. The final 40ft structure comprised 10,000 organically grown bricks, and could withstand winds of up to 65mph. The collaboration — which included Evocative, academics, architects, structural engineers, metals and fluid mechanic experts — helped to prove the validity of this low-carbon biological technology. Its future uses are now being tested and enhanced for other built environment functions.

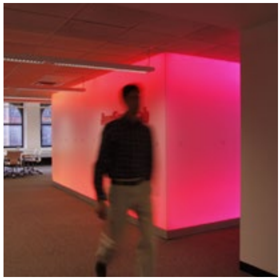
Arup's SolarLeaf house pilot project integrates bio-reactive façades onto buildings to generate renewable energy from algal biomass and solar thermal heat. The biomass and heat generated by the façade are transported by a closed loop system to the building's energy management centre, where the biomass is harvested through floatation and the heat by a heat exchanger.

Because the system is fully integrated with the building services, the excess heat from the photobioreactors (PBRs) can be used to help supply hot water, to heat the building, or stored for later use. Carbon to feed the algae can be taken from local combustion processes (such as a boiler in a nearby building), creating a short carbon cycle and preventing carbon emissions entering the atmosphere. As the microalgae bioreactors grow, they can help provide shading for the building and contribute to lowering cooling needs and limiting the urban heat island effect. As lead consultants on the project, we developed the system in collaboration with SSC Strategic Science Consult and Colt International in Germany.

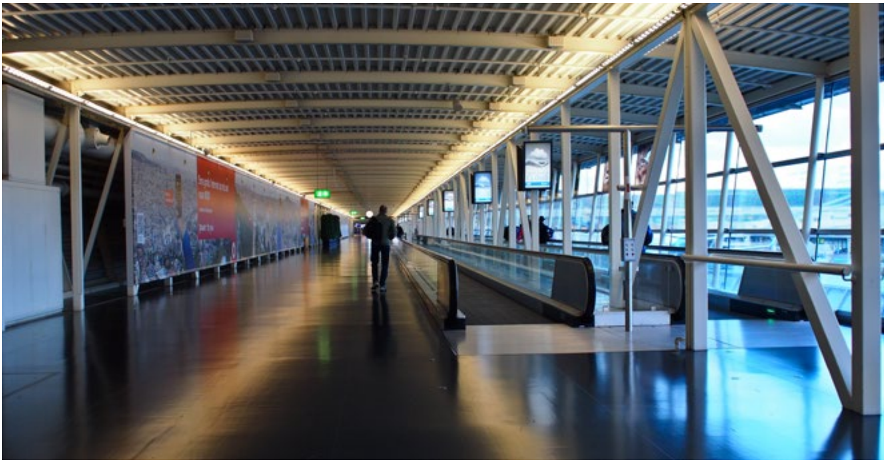
Replacing traditional solutions with advanced technology

New and advanced technologies including innovative materials, products and services are being designed for longer lifecycles, modular repair, flexible upgrade and active disassembly.

3D printing and high-performance technologies such as LEDs now replace older non-renewable technologies. These new technologies can be monitored and maintained using intelligent digital solutions such as the internet of things



LED lighting, Arup Soundlab Chicago (top) Additive Manufacturing, 3D printed steel node, Arup (bottom)



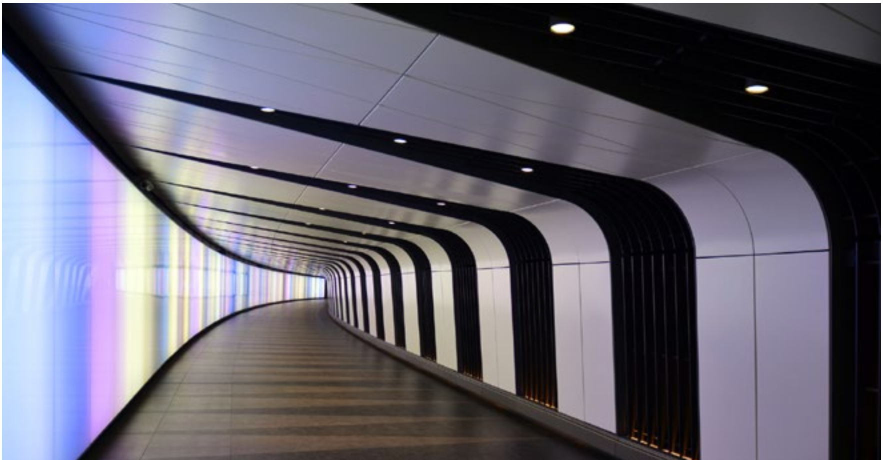
Philips provides lighting as a service to Amsterdam's Schiphol Airport on a lease basis

(IoT). LEDs are significantly more cost- and energy-efficient, more durable and longer lasting than conventional incandescent light bulbs. One LED light bulb can replace 25 incandescent light bulbs. They are also recyclable, low maintenance and contain no toxic materials.

Using the latest 3D printing techniques Arup produced a design for critical structural steel elements. This innovative technique enhances both design and production processes to allow manufacturers to create complex, individually designed pieces and print them directly in metal. The approach also produces smaller, lighter elements that deliver the same function and strength as those created by traditional methods. Our research shows that for construction projects, this could mean a reduction in the overall weight of a structure of 40% or more. This could translate into significant cost, waste and carbon emission reductions.

Replacing product-centric delivery models with new service-centric ones

Performance-based contracts focus on delivering an output or service instead of selling a product. Through this model, components such as lighting or office furniture are leased to an asset owner or operator, who is incentivised to return the products at the end of their useful life for repair, reuse or recycling. The customer only pays for the desired outcome



The system uses light-emitting diodes (LEDs) which are expected to cut the airport's energy consumption by as much as 50%

– such as the lighting of a space – and not the installation, maintenance or ownership. This maximises use of products and cuts waste.

Philips' 'pay per lux' solution provides lighting as a service to Amsterdam's Schiphol Airport on a lease basis. Philips is responsible for the performance of the lighting for the duration of the contract.

Specially designed light fixtures are easier to service and maintain making them last 75% longer than conventional alternatives. Individual component parts can be easily extracted and repaired, minimising the need to replace whole fixtures. This reduces the consumption of raw materials.

The system uses energy-efficient light-emitting diodes (LEDs), and is expected to cut the airport's energy consumption by as much as 50%. The service operates via a collaboration between the Schiphol Group, the energy service provider Cofely and Philips. This multi-party arrangement also enables the real-time management of the service, helping to ensure it is as reliable and effective as possible.

Philips provides a similar solution to the new National Union of Students (NUS) building in London. Here Philips retains ownership of all the equipment and leases its lighting services on a 15-year contract basis. Included is a guarantee to maintain it at at least 70% of its original output standard. Online monitoring helps to reduce maintenance costs. Financial incentives mean that both parties are rewarded for


ARUP
LHR6

Circularity at Scale

"We need to get the whole supply chain together to identify overlapping obstacles, remove the barriers, show the opportunities and discuss how to work together. Contractors might see the benefits of CE but mainly they see the risks; we need to remove these and show them the opportunities. We need to engage with them about where they get their materials, how much they use and what can be reused."
—Nille Juul-Sørensen, Arup

While the prospect of linking all aspects of the built environment through a fully inclusive and comprehensive circular economy remains a challenge, there are plenty of circular examples at each level of the industry. There are also plenty of opportunities to integrate these further, bringing benefits to all parties involved.

Currently, circular practices tend to occur at the individual component or asset level. They include modular, prefabricated and off-site construction, design for disassembly, materials reuse and recycling, and designing out waste.

A global shift to the circular economy is still some way off but the industry is starting to see the value and is adapting accordingly. What is needed is a coherent vision for a collaborative roadmap that can translate high-level principles of the circular economy into industry-specific metrics, processes and dynamics.

Technological advances and other innovations are already fuelling new design approaches, as well as organisational, regulatory and commercial mechanisms that support the circular economy model. Ensuring that benefits flow to everyone in the value chain also requires changes at system-scale: to governance, procurement, financial and delivery mechanisms and incentives.

Collaboration and exemplars are essential to guide this process and give confidence to all stakeholders. Policy and

Left: Project Meteor uses off-site construction techniques and standardised components to minimise waste and costs

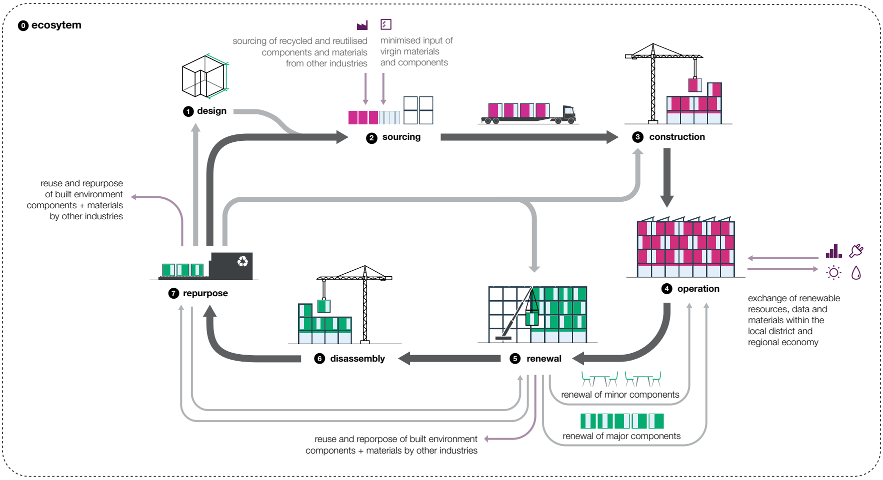


Figure 4: Application of Circular Economy Principles to Commercial Property

norms for governance and procurement will help to create the enabling environment needed to catalyse action.

Buildings

"In the built environment, it's all about maximising utility of resources — extending product life or providing a proper end-of-life recovery."
—Nick Cliffe, Innovate UK

At the building level, a possible application of the circular economy in the property sector can be illustrated with the example of commercial property (Figure 4 above).

The market for commercial property is closely coupled to global and local investment and economic cycles. There is pressure on assets to respond to changing market conditions. Asset owners and developers are looking to minimise the construction cost of buildings and the financial impact of retrofitting and renewal cycles. Owners are also under growing pressure to lower operational costs and improve performance. Furthermore, in many markets there are high levels of regulation aimed at minimising negative externalities such as carbon emissions.

Arup has produced a circular economy model of the commercial property development cycle to identify where circular approaches offer the greatest opportunity to increase efficiencies and reduce costs and environmental impacts. The descriptions provide a vision for how this system would function in practice.

0. Ecosystem

In a circular economy, buildings will be designed for a whole lifecycle and not simply an end use. Stakeholders will collaborate on cloud-based BIM models with analytical software that clearly visualises a proposal's externalities. Policy and incentives will encourage clients to issue full lifecycle contracts from design to operation and disassembly as well as pushing their ambitions in achieving holistic lifecycle certification and awards. Components and structures will often be leased rather than purchased. Performance-based contracts will see tenants and landowners pay for a service such as lighting rather than individual fittings or materials. Circularity will be embedded in all parts of an ecosystem. This will ensure that individual assets are flexible, interchangeable and highly customisable, and will enhance users' experience of the environment.

Design decisions such as optimising disassembly and reuse from the beginning of the programme have implications for the operation, renewal and repurposing of the building and its components. In the circular model, a building's construction will be integrated with the resource and reuse cycles of other industries. In operation the building will use renewable sources and, where possible, locally available used material streams. This will make it more resilient, and will lower risks to investors. Buildings will also be used flexibly 24/7 with high levels of occupation during the day and night.

1. Design

A circular building will be more than just a structure providing space and shelter; it will accommodate future change such as remodelling, expansion or disassembly.

Modular construction,
WikiHouse, London (top)
Pre-cast concrete (bottom)

A multi-story modular housing block in Stoke Newington, London, UK (top) Low impact LED lights (bottom)

Open-source design will become standard practice and architects, engineers and designers will share their designs and build on each other's work. The mind-set of building designers will change and structures and buildings will be reused and retrofitted where possible before new structures are considered. Design will be more than just form, structure and space. Operation and performance will be embedded into design processes, to incorporate energy-efficient principles such as passive design and minimised externalities.

2. Sourcing

The extraction of materials may be dramatically curtailed in future, as resources become scarce. Modularity and adaptability will be key components of design in a circular built environment. Buildings will be constructed from flexible, durable, reused and reusable parts. The use of highly sustainable biomaterials will expand. And non-standardised materials and components left as a long-term legacy of the linear economy will be reused as much as possible. For example, in-situ concrete components could be transformed into other building modules.

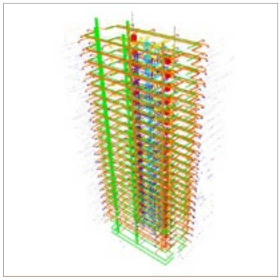
3. Construction

The word construction in a circular world will be used in the context of assembly. The physical casting of bespoke elements, such as concrete casts or steel components, may no longer be standard practice as the industry moves to increased flexibility. However, 3D printing could challenge this trend with the introduction of resins and substrates made from renewable or reusable materials.

Off-site manufacturing and prefabrication will help to eliminate waste from construction sites. Designs and detailing will be done so as to minimise material use.

4. Operation

All buildings and structures will be designed to high efficiency standards, minimising externalities and environmental impacts. These will include structures with internal circular resource cycles such as water capture and filtering. Buildings will be net producers of energy. They will have battery storage and low-impact fit-out components such as LED lights and strategies that eliminate wastage of energy and materials. Tenants and building users will lease components and services, paying only for the service rather than for individual fittings. The structure and components will be regularly managed with preventative maintenance techniques. These will be made possible by low-energy and low-cost sensor technology that helps reduce costs, minimise disruption and maximise the useful life of the building and its fittings. Flexible use and sharing will help to raise occupancy rates.



Building Information Modelling (BIM) will allow users to collaborate on cloud-based models

5. Renewal

The functions of, and demands made on, buildings and structures are constantly changing and yet today they are static and rigid by design. In the circular world, buildings will be dynamic platforms enabling greater adaptation and flexibility. For instance, designs will allow for easy access to building services or include demountable and reconfigurable façade systems. Circular buildings will be retrofit- and upgrade-ready. This will minimise the time and cost for renewal and eliminate waste and other outputs. Policies and industry standards will ensure components from different manufacturers and providers are interchangeable.

6. Disassembly

Demolition will be minimised in a circular world. Design approaches will make novel building designs possible while allowing for change and disassembly. Lifecycle BIM models will allow stakeholders to easily take buildings apart, expand or contract them, or to redesign them using the same components. Structural pieces may be transported using standard vehicles and containers. As a result, buildings will be highly mobile, versatile and flexible – lengthening their useful lifespans.

7. Repurpose

The circular built environment will make maximum use of components and materials, circulating them between buildings and projects and maintaining them at the highest possible value and performance. After a certain period of time, components will no longer be suitable for use in

A New House of London, UK

the same context. They will then need to be recycled and remanufactured into other less structural parts or other products for other industries. Every material part and component will be carefully tracked through its lifecycle and recorded in lifecycle BIM models. Established value networks and second-use strategies will ensure all components are adequately used in other industries, minimising the value lost and ensuring numerous repurpose cycles.

In a circular economy, buildings will be designed for a lifecycle and not simply an end use. Stakeholders will collaborate on cloud-based BIM models with analytical software that clearly visualises a proposal's externalities. Policy and incentives will encourage clients to issue full lifecycle contracts from design to operation and disassembly as well as pushing their ambitions in achieving holistic lifecycle certification and awards. Components and structures will often be leased rather than purchased. Performance-based contracts will see tenants and landowners pay for a service such as lighting rather than individual fittings or materials. Circularity will be embedded in all parts of a structure. This will ensure that individual assets are flexible, interchangeable and highly customisable, and will enhance users' experience of the environment.

Design decisions such as optimising disassembly and reuse from the beginning of the programme have implications for the operation, renewal and repurposing of the building and its components. In the circular model, a building's construction will be integrated with the resource and reuse cycles of other industries. In operation the building will use renewable sources and, where possible, locally available used material streams. This will make it more resilient and will lower risks to investors. Buildings will also be used flexibly 24/7 with high levels of occupation day and night.

The example above highlights the potential for the circular economy to change the ecosystem and value chain for the design, construction, operation, renewal and repurpose of buildings. It requires designers and investors to take a longer-term view, focusing on the lifecycle of the building and carefully mapping the past, current and future usage of materials and components. This involves high levels of collaboration and information exchange. It requires tools and incentives that enable investors to receive a financial return on decisions that affect not only the selling and leasing of properties and spaces, but also their end-of-life usage and repurpose. Additionally, new business models are needed that increase asset use and foster more use of renewable resources and components.

The circular economy was also identified as a cross-cutting theme in the Greater London Authority (GLA)'s London Infrastructure Plan 2050. It was seen as a way to increase integration across the city's energy, water, waste, mobility, green and blue infrastructure, housing, and digital connectivity sectors. In the Plan, Arup calculated that transitioning to a circular economy could save the city £5bn in waste management services alone by 2050.

Arup also collaborated on the *New House for London* project, a prefabricated design for adaptable mixed-use spaces that featured at the 2015 London Design Festival. This uses a low-voltage direct current (DC) energy network that can operate independently of the main grid. This would enable inhabitants to feed the energy they generate back onto the grid, enhancing resilience and providing redundancy to the wider system. In addition to being low-energy and sustainable, the design provides a low-cost solution to tackle the housing shortages and affordability challenges many cities face.

In London, circular economy opportunities in the built environment will add £3-5bn to GDP by 2036. Exemplar interventions identified for London include:

Modular construction using 3D printing and additive manufacturing could reduce structural waste and build times, delivering a benefit of over £800m per year

Making more use of buildings through peer-to-peer renting, office sharing, and multi-purposing buildings could save over £600m a year by doubling the utilisation rate of 20% of buildings by 2036

Design for building disassembly, material management and re-use with efficient disassembly techniques, material passports, innovative business models and reverse logistics could save over £200m.

Circular Economy is seen to increase integration of city systems

Arup is working in collaboration with The Built Environment Trust as part of the London Design Festival 2016, to design and construct the Circular Building, which will be located outside the Building Centre in September 2016. This is a prototype for a new approach to housing in which all components and materials can be recovered and re-used at the end of the building's life.

Infrastructure

"The circular economy approach helps build better relationships with customers. In the built environment, it's a business opportunity and a necessity — you have to stay ahead, if you don't, someone else will come and take that business away. But you have to find the right customers and partners. You can't do this on your own."
—Forbes McDougall, Veolia

Circular infrastructure can help to achieve holistic integration of circular economy principles along the design and operation

Scotland’s Forth Replacement Crossing

of assets. These include new models for operation, asset utilisation and maintenance strategies and tend to focus on minimising negative externalities, increasing longevity, and integrating network systems and components to maximise circular resource and material flows. For infrastructure, this may include the optimisation of current design-build-finance-operate-maintain (DBFOM) approaches, including extended concession periods and optimised resource and recycle plans. Circular approaches to infrastructure may also create new business opportunities. New relationships may form between industries and stakeholders not normally brought into contact, e.g. designers and demolition companies.

Many of the same principles and approaches apply to buildings and infrastructure. As with buildings, decisions must be taken early in the design process to ensure circularity is integrated throughout the lifecycle of an infrastructure asset. Coordination and collaboration are essential to achieving this.

HS2 have begun to embed circular economy principles into their sustainability policy and recently announced a competitive tender to identify existing work and further opportunities where circular economy principles can deliver value for the programme.

Under pressure to decarbonise, integrate variable renewable energy sources and meet increasing demand, the energy industry is already innovating how it operates. In

Olympic Stadium, Stratford, London: 98% of demolition material was reused or recycled

the UK ESCos (Energy Service Companies) offer energy as a service to customers, rather than simply supplying kWhs. Energy services include on-site generation, microgrids, battery storage, electric vehicles and energy efficient appliances. Off-grid energy infrastructure can help communities and neighbourhoods to produce, store and locally distribute their own energy and resources, encouraging sustainable energy production, reducing reliance on the grid and increasing local resilience.

ESCos often use performance contracting, making the company responsible for delivering a guaranteed service or energy saving with remuneration directly tied to energy savings achieved. ESCos can also finance, or assist in arranging financing for the operation of an energy system by providing a savings guarantee.

Monitoring and assessment technology is critical to maximise the performance of infrastructure and facilitate repair and prolonging of assets' lives. To ensure the smooth operation of the Forth Replacement Crossing in Scotland, Arup developed a simple-to-use, fully integrated structural health monitoring system (SHMS) equipped with 1,000 sensors to give advance warning of structural problems and allow targeted inspection and intervention. In addition to reducing resource use, the intelligent system will make maintenance more efficient, prolonging the bridge's life and enhancing the overall resilience of the two bridges.

Athlete's Village, Stratford, London: a housing development of over 2,000 units

Decommissioning of large oil and gas assets such as offshore platforms increasingly provides opportunities for reuse, remanufacturing and recycling. Advanced information sharing platforms can help stakeholders to buy and sell assets and components, extracting value from decommissioned infrastructure, thereby reducing wastage and landfill. Pipelines and other large components may also reused in other energy contexts such as carbon capture and storage network. Calculations by Green Alliance and the Zero Emissions Platform (ZEP) suggest that reusing pipelines could generate a value of £1.63m if reused for Carbon Capture and Storage (CCS) and £26,000 if reused for construction.[12]

Opportunities to reuse engines, pipes, foundations, beams and other large industrial equipment and materials exist across the built environment. During London's Olympics in 2012, the Olympic Delivery Authority (ODA) set a target that at least 90% of demolition material must be reused or recycled. In the end, 98% of the materials were re-used and 700,000 cubic metres of soil were decontaminated and cleaned for reclamation and reuse. 400,000 tonnes of carbon dioxide was saved, 100% of materials were diverted from landfill and 62% of that waste was reused, recycled or composted. Surplus gas pipelines were also used as structural steel in the construction of the Olympic stadium.

The integration of circular economy principles at city scale

These strategies resulted in major carbon, cost and materials savings, making the Games, the ‘most sustainable ever’ as targeted by the organisers.

As part of the legacy strategy, many of the arenas and facilities in the Olympic Park were designed for flexibility and reuse. Since the end of the games, sporting stadia have been converted into public clubs and local industry hubs. The main stadium is now used by West Ham football club. And the athletes’ villages became East Village, a housing development of over 2,000 units comprising market priced private rentals and affordable housing. The ArcelorMittal Orbit sculpture was even turned into a giant public slide.

Cities

“When cities change, it is usually triggered by some new demand. The circular economy is likely the next big demand, and cities will need to learn how to respond.”

—Dr. Jeffrey Pittaway, Imperial College London

Cities comprise systems within systems, with multiple overlapping networks that interact at different scales. Cities have density and scale, and they are resource-intensive. Typically, they are also centres of innovation and collaboration, attracting skilled individuals and businesses. Consequently, city governments are well positioned to provide the right environment for the transition to the circular economy. Cities can also provide financial support and resources to help accelerate the transition. Alternatively, they can create connections and opportunities that lead to co-creation of new initiatives or novel business models.

Several global cities are proving their commitment and aptitude for developing the circular economy. Some approaches focus on built environment solutions such as the establishment of circular economy buildings and business districts, as in Amsterdam. While other cities, like London,

Model of Buiskloterham, Amsterdam

have emphasised the potential for the circular economy to drive economic development and job creation.

Several cities and communities have initiated targeted programmes that apply circular economy principles in different ways. For example, Paris mayor Anne Hidalgo refers to the city's circular economy plan as "a social and solidarity economy".[13] Paris' approach focuses on socio-economic priorities such as sharing over profit-making, collective intelligence and mobilising local authorities and citizens.

In the UK, Peterborough has a stated ambition to become the country's first circular city.[14] The organisation behind the programme — Peterborough DNA — builds on concepts such as systems thinking, urban metabolism and biomimicry. It employs a collaborative, bottom-up approach in which local stakeholders play a central role in designing and managing circular approaches. It focuses on city-wide systems and networks such as water, energy and materials, while incorporating aspects of local skills, transport, education, health, communities, recreational activities and other city services. The Share Peterborough platform is an online service designed to increase collaboration and use of assets across the city by enabling local businesses to share waste streams, machinery, equipment and personnel.

Amsterdam is accelerating its transition to become one of the world's first circular economy cities. Analyses such as *Towards the Amsterdam Circular Economy* and the City Circle

The Seoul Metropolitan Government launched Sharing City Seoul in 2013

Scan propose practical steps and business models to aid the shift at all scales, from individual residential blocks to the city scale and beyond.

The former industrial area of Buiksloterham in Amsterdam is being designed and built to circular economy specifications by the municipality in collaboration with local businesses and community organisations. The new citizen-led development will incorporate 3,500 homes and 200,000m² of workspace, and will serve as a living lab for smart, circular development. It will be zero-waste, emission-free and entirely self-sufficient in energy. All products and materials will be recovered for reuse, repair and recycling.[15]

Amsterdam's city council supporting this development by providing self-build plots in attractive locations. Arup recently worked with local architects, new plot owners and residents to design six self-build houses that form part of the complex. The lessons from this project are now being applied to develop design principles for new urban development. These are based on a reversed development model in which citizens define and co-design their environment. This encourages a shift away from traditional fixed infrastructure and centralised governance, towards distributed and decentralised approaches, citizen-driven decision-making, local manufacturing, on-site energy generation and storage, and customisable, modular buildings.

ReGen Villages, by architectural collaborative EFFEKT, is a new visionary model for the development of a series of off-grid, integrated and resilient eco-villages

The ReGen Villages project is another example of a circular community concept. It aims to create fully self-sufficient communities, with all food grown on-site using aeroponics, aquaponics, permaculture, food forests, and high-yield organic farming in greenhouses.

All household waste will be composted using waste-to-energy systems and fed to livestock or soldier flies (which will be used in turn as a food source for fish). A mixture of geothermal, solar PV and thermal, wind energy and biomass will feed into a smart distributed energy network, and non-compostable waste will be converted to energy and water via a biogas digester. Water will be recycled and upcycled to be used by households, and in livestock and food production.

ReGen is developing early stage initiatives in several countries including the Netherlands, Sweden, Norway, Denmark and Germany.[16] Arup recently signed a contract to work with ReGen to define the economic, ecological, aesthetic and technical feasibility of the development.

Seoul Metropolitan Government (SMG) launched the Sharing City Seoul programme in 2013. The initiative aims to design and support sharing businesses to minimise waste and underused capacity, cut municipal costs and encourage new business opportunities and relationships. Examples include platforms for car sharing and parking, and for lending and borrowing underused goods. There is also a service to match students needing accommodation with local residents who have spare rooms in their homes.

Spoon recycling for reuse in 3D printing

Food waste supermarket in Denmark

Regional and national

"To drive the circular economy in the built environment, we need a combination of incentivisation and regulatory mechanisms for designers, developers, and other value chain members that join up actions and promote a life cycle approach."
—Dr Kristian Steele, Arup

While cities are powerful enablers of the circular economy, few have the administrative powers to drive changes and implement circular practices directly. Policy and regulatory support from regional and national governments can provide cities and industries with the incentives and, in some cases, funding to drive the circular agenda.

Scotland's Making Things Last strategy sets out the Scottish Government's vision and objectives for a circular economy. The strategy builds on Scotland's earlier zero-waste and resource efficiency agendas and covers four main categories:

Food, drink and the bio-economy; Remanufacture;
Construction and the built environment;
Energy infrastructure.

The initiative addresses the whole lifecycle of products and materials, from waste prevention through to design, repair, remanufacture and recycling.[17]

To tackle food waste and poverty, the French government has recently legislated to prevent large supermarkets throwing away or destroying unsold food, forcing them instead to donate surplus food to charities. The new law also facilitates donations from factories directly to food banks. This had previously been difficult to arrange due to regulations on waste. Italy has introduced a similar law which incentivises rather than deters businesses from donating food. And Denmark has opened a food waste supermarket, which sells surplus produce in Copenhagen.

The Danish government has also introduced public procurement regulations to assist the shift towards a circular economy. The Partnership for Green Public Procurement (GPP) comprises ten Danish municipalities, two regions and the Ministry of the Environment and Food. With a combined volume of procurement of around €5bn, the partners have committed to the greening of specific procurement groups to fulfil criteria including recyclability, chemical use, and product lifespan.

Under the programme, the city of Copenhagen has a target for 90% of food served in public kitchens, schools, hospitals and nursing homes to be organic and seasonal. Eco-certification of products, sourcing from local suppliers, training, education and ongoing engagement between the scheme's participants have all helped to drive the success of the programme.

Such an approach could be applied to the built environment. Opportunities to learn from, and share, experiences can accelerate the industry's own transition.

At the regional level, the European Union (EU) recently announced its Circular Economy Package, after some criticism and delay. Closing the loop — An EU Action Plan for the Circular Economy covers 54 initiatives under six headings and five priority sectors. These include plastics, food waste, critical raw materials, construction and demolition, and biomass and bio-based materials.[18]

Under the plan, the Commission proposes expanding the use of the existing Ecodesign Directive and extending

Chinese Association for the Circular Economy (top) 90% Materials recovery in Japan (bottom)

producer responsibility schemes to promote durable, reparable, recyclable and upgradeable products. Financial support will also be provided, including €650m from Horizon 2020, and €5.5bn from European Structural and Investment Funds (ESIF).

In response to increased resource depletion, pollution and ecosystem degradation, the Government of the People's Republic of China launched the Circular Economy Promotion Law in 2009. Within it are national plans for safe municipal solid waste treatment, energy savings and emissions reductions.

The Chinese government is now investing in, and providing support for, activities including the Chinese Association for the Circular Economy (CACE). This is a steering group mandated to promote best practice in recycling, cradle-to-cradle development cycles, and reclamation of waste materials from across China's industrial and retail sectors.

Due to Japan's lack of natural resources, the circular economy is well established in Japanese law and culture. Policies to reduce oil dependency, waste and environmental impacts, and to promote public awareness and education have long been the norm.

Japan's metal recycling rate is 98%, while 72% of polyethylene terephthalate (PET) bottles are recycled (compared with 48% in Europe and 29% in the United States). Almost 90% of materials are also recovered from electronics, which are then used to produce new appliances. Recycled material is found in textiles, sheeting, industrial materials and household items – or shipped elsewhere to make products such as toys.

Global

"To make this [the circular economy] work in the built environment, we need a new threshold of trust. There needs to be a mutually shared benefit."
—Munish Datta, M&S

Industries and governments across the globe are starting to recognise the benefits of shifting to more sustainable forms of economic growth and creating value.

A global circular economy would have to adopt a systems approach in which assets, processes and systems operate both singularly and as part of an integrated whole. In a circular global economy, this would be achieved by formal and informal policy and governance mechanisms designed to avoid creating winners and losers. These would also need to ensure that risks and benefits were fairly distributed throughout the value chain.

Policy encourages directional change and gives confidence to delivery partners

Regulatory tools could be used to further catalyse action, for example on procurement, waste and extending product life. They could also help to expand the circular economy skills base and fund educational programmes and skills transfer. Governments and industry both have a role to play in building and disseminating best practice guidance and information exchange.

A global vision would be underpinned by the evaluation of interdependencies between systems and their associated impacts. For example, a reduction in waste and waste processing could impact downstream industries and service providers. New leasing or performance business models may have legal, structural and financial effects on the ownership of assets, contractual arrangements and payment mechanisms. Things like this could have knock-on effects on how businesses are structured.

Incentives will be needed to drive innovation and to scale up component initiatives to the national, regional and global scale. Trust must be built through collaboration and shared learning about operating under new business models and in new regulatory environments.

It will take time for industries and governments to recognise the value of circular practices and to adapt their models, structures and working practices. New prototypes and case studies will help to build confidence in taking on the challenges and in developing the skills to deliver circular projects and initiatives at scale.

Quantifying the benefits of projects and case studies will continue to illustrate the economic, social and environmental value of the circular economy. Digital technologies will provide virtual spaces to share data and experiences and develop partnerships.

7S MODEL

The concept of building in 'layers' was first proposed by architect Frank Duffy in the 1970s, and developed by Stuart Brand in the 1990s. Buildings, they said, are made of separate and interlinking layers, each with a different lifespan. Brand's widely-known model includes six layers: Site, Structure, Skin, Services, Space, and Stuff — see Figure 6. The diagram below illustrates how the layers model would function in the built environment context. An additional layer — System — has been added to show how this approach would be applied beyond the scope of a building, for example in the context of a district or city.

Building in layers means that each element may easily be separated and removed. This facilitates reuse, remanufacture and recycling. For example, facades or heating systems may be designed and fitted as independent entities, integrated with other building systems but not entwined with the fabric of the building. This also avoids large scale wastage of assets, lowers resource use and other environmental impacts, and obviates the need to construct entirely new buildings and assets. Building in separate layers, with different lifespans also allows each element to be repaired, replaced, moved or adapted at different times without affecting the wider entity, e.g. the building or infrastructure asset. This reduces unnecessary obsolescence and increases flexibility of use and longevity over time.

The potential lifespan of each layer descends from the longest at the System level, to the shortest at the Stuff level.

System

System includes the structures and services that facilitate the overall functioning of the system, e.g. roads, railways, electricity, water and waste water systems, telecommunications, parks, schools, digital infrastructure

Site

Site is the fixed location of the building

Structure

Structure is the building’s skeleton including the foundation and load-bearing elements

Skin

Skin is the façade and exterior

Services

Services are the pipes, wires, energy and heating systems

Space

Space is the solid internal fit-out including walls and floors

Stuff

Stuff is the rest of the internal fit-out including the furniture, lighting, and ICT.

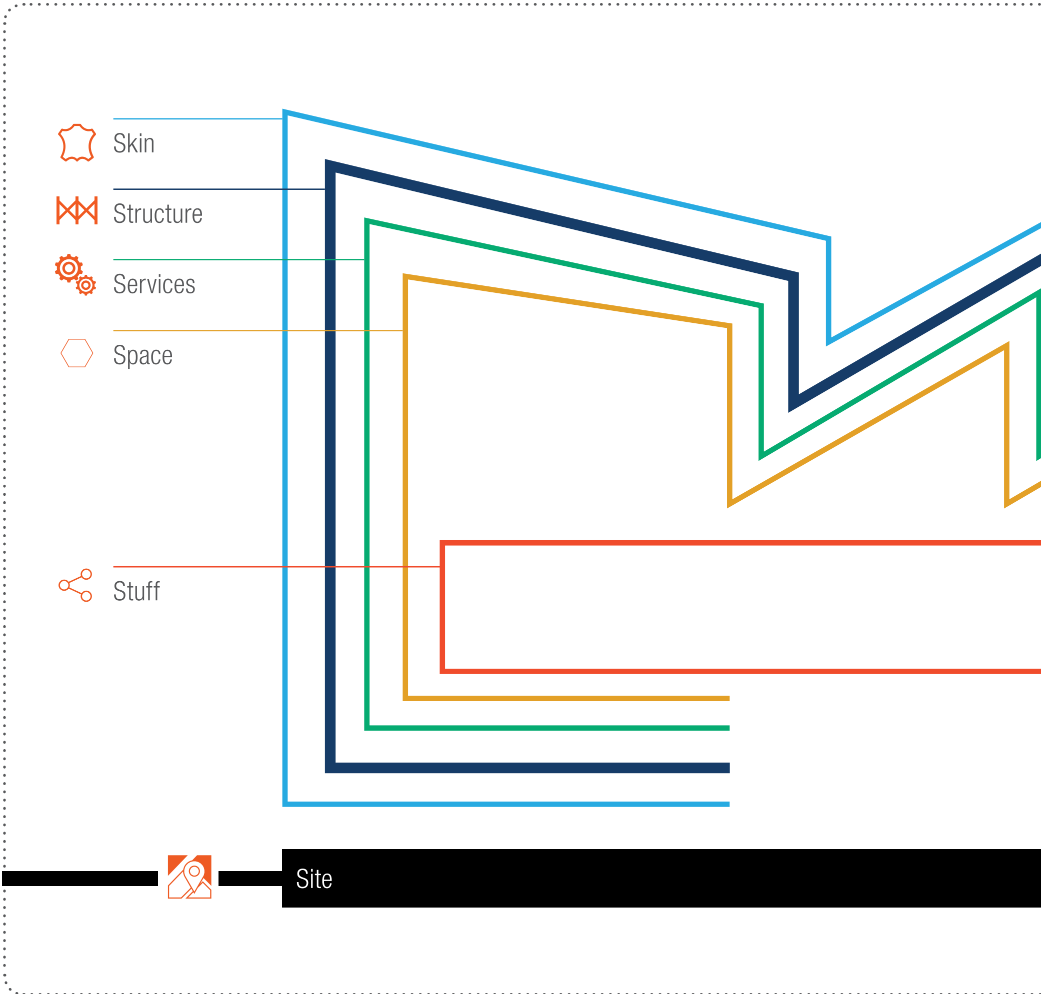


Figure 6: 7S illustrative example (Source: Stuart Brand's *Shearing Layers, from How Buildings Learn: What Happens After They're Built* (Brand, 1994). Adapted by Arup, 2016).


System

	Regenerate	Share	Optimize
System	Extraction and reuse of biological resources via anaerobic digestion to create and supply energy onto the grid	Sale of energy back to the grid	Optimisation of transport links between built assets. Integration of low carbon systems. Designing out waste strategies (HS2)
Site	Detoxify and regenerate brownfield land to revive the biosphere (Old Oak and Park Royal Development, London)	Online platforms to facilitate space sharing. (The Collective) Open source data platforms for sharing designs (WikiHouse)	Use of localised renewable energy sources and distributed networks.
Structure	Nature-based design solutions. Low impact materials, design and construction (Madrid + Natural)	Reuse of structural elements of buildings, e.g. reclaimed timber or steel beams	Design for longevity and adaptability (White Collar Factory)
Skin	Integration of green walls and surfaces. Extraction of green walls for composting and reuse	Pool or share assets, equipment and personnel. Design for disassembly (Globechain)	Leasing of façade in performance based contracts (Frener & Reifer façade)
Services	AD recycling biological nutrients and biogas (Nestlé AD plant)	Reuse of building components e.g. pipes, metals, electronics	Leasing of lighting and energy. Sensor-based lighting (Phillips pay per lux)
Space	Use biodegradable and compostable materials (Ecovative)	Maximising space utilisation (HeadBox)	Design for flexible use. Maximise use of daylight and natural ventilation
Stuff	Use biodegradable and compostable materials (Ecovative)	Maximising space utilisation (HeadBox)	Design for flexible use. Maximise use of daylight and natural ventilation

Loop	Virtualise	Exchange	
Renewables and circular resource flows (energy, water, waste etc). Adapt use over time, e.g. commercial to residential	Virtual/digital storage via cloud systems. Smart systems to improve systems integration	Integrated circular city design approach (Regen Villages)	System
Retrofit and reuse existing buildings and assets for different uses (Tata Steel)	Open source design via openly accessible online platforms (WikiHouse)	Construction using alternative sustainable and low impact materials (Hi-Fi mycelium tower)	Site
Design for disassembly. Regeneration of buildings for mixed use	Internet of Things / ICT / BIM to monitor performance and facilitate maintenance and repair	Use sustainable materials and approaches (Sky Believe in Better Building)	Structure
Modular design and off-site prefabrication (Sky Believe in Better Building)	BIM to monitor performance and facilitate repair (Hong Kong sludge treatment plant)	Integration of bio-façades (SolarLeaf House)	Skin
Open design and operating standards. Rainwater harvesting, grey water recycling, battery storage on-site	Smart sensors. Monitor and deliver maintenance services remotely (Forth Replacement Crossing)	Shift to services over ownership. Internet of Things. LED light replacement	Services
Remanufacturing of products and components (Cat Reman)	Video and virtual conferencing	Natural lighting and ventilation solutions	Space
Remanufacturing of products and components (Cat Reman)	Video and virtual conferencing	Natural lighting and ventilation solutions	Stuff

Enabling the Circular Economy

Through our research and discussions with partners and experts, we identified four key enabling factors critical to the development of the circular economy.

5.1 Education, awareness and communication

"While we are always looking to minimise waste on our projects, the language and communication side (of the circular economy) can be alienating, meaning it is hard to get people on board because it seems like another form of sustainability. People are still trying to get their heads around the direct benefits of participating."
—Jocelyn Horwood, Skanska

To unlock the circular economy, stakeholders throughout the value chain need education and more awareness to shift their mindset. Designers and developers must be taught to think in a way that encompasses the whole lifecycle of an asset, from how it will perform throughout its service life, to how it can be taken apart and its component parts reused. Similarly, operators of buildings and infrastructure need to understand how approaches such as access and leasing models will affect the way they use, procure and pay for services.

Left: Upton Square, Northampton, UK

Cross-industry collaboration provide platforms to exchange information

Cross-industry collaboration and sector networks will provide platforms to exchange information, experiences and best practice. This will help reach mutual agreement on how to progress individual, organisational or joint agendas. Veolia, for example, is partnering with the flooring solutions firm Tarkett Group to collect and process flooring off-cuts for reuse in Tarkett's production and manufacturing processes.

Quantifying the economic, social and environmental benefits of specific circular economy initiatives will help all parties to appreciate its value to their business and sector. This will, in turn, help them to make the case for investment or contractual adjustments to facilitate a broader transition.

Case studies are needed to put business models into context, and to provide credibility and confidence that alternative approaches are not only feasible but also desirable. Sharing information will continue to demonstrate the benefits, build knowledge and raise the profile of circular projects, and connect partners seeking collaborative opportunities.

Policy encourages directional change and gives confidence to delivery partners

5.2 Policy and regulation

"The shift towards a circular economy will likely come from business, though there is a role for government to raise awareness, address real barriers and facilitate information availability in support of business."

—Department for Environment, Food & Rural Affairs (Defra)

Policy and regulation help to create an enabling environment that encourages directional change and gives confidence to investors and other delivery partners.

The built environment sector would benefit from strengthening industry targets for waste and reuse, as well as incentives to promote extending product life and remanufacturing. Such an approach could help to revitalise ailing manufacturing sectors in countries like the UK.

Policy is also needed to help remove barriers, such as altering the definition of waste to facilitate re-use and minimise landfill. This would also help to support new markets for secondary materials, for example, and unlock new revenue streams.

Workforce up-skilling (top) and BIM (bottom)

Policy can support organisations seeking to train or up-skill their workforce. New policy measures can also help to drive innovation by providing incentives (to develop demonstration projects, for example) and by creating a more secure environment for investors.

In addition, policy interventions can accelerate change and promote procurement that favours whole lifecycle approaches. For example, the UK Government's target for all public sector asset procurement to achieve BIM Level 2 by 2016 is driving collaboration on building design, increasing efficiency across the construction industry. BIM Level 2 stipulates that all digital information shared through BIM should be inputted in a consistent format across all disciplines.

Targets for BIM Level 3 have not yet been confirmed but are likely to include integrating BIM models into a single project model including construction sequencing, cost and lifecycle management information. This will eventually combine with the internet of things, advanced data analytics and the digital economy under the umbrella title Digital Built Britain (DBB).

Industry advocacy is also needed to facilitate and steer regulation on procurement. As digital technology spreads, governments are coming under increasing pressure to regulate public data sharing and security practices. Embedding circular economy thinking into standards will ensure that governments are better equipped for a more integrated and resilient digital future.

While policy will provide a valuable signal to the market — helping to catalyse action – the development of circular economy practices at scale is expected to come from industry itself.

5.3 Technology and innovation

"Innovation in product design and access to more data will drive better developments. Getting more out of what we already have will be important. Better connecting what we do, particularly when we think of our supply chain systems, existing built assets, and waste/resource flows across our developments, will help us deliver more for less."

—Dr Kristian Steele, Arup

Technological advances are accelerating the development of the circular economy. Sharing platforms such as FLOOW2, Globechain and HeadBox are helping to address the issues of under-used assets and superfluous capacity – facilitating trust and collaboration on the reuse of materials and assets. Applying more connected and intelligent technologies like BIM in the built environment will further improve information-sharing and transparency. This will in turn help to address inefficiencies in how assets are built and operated, and enhance flexibility, redundancy and resilience.

The way people inhabit the built environment and consume related services is also changing. The co-living model, for example, is growing in popularity in major cities where rising populations and constricted housing supply have contributed to high rental prices. Ubiquitous digital connectivity, especially in cities, is also accelerating the desirability of sharing and leasing models over models of ownership.

Flexible working and shared living arrangements are altering the way people interact with the built environment. The design and construction industry is beginning to adapt in response, with a greater focus on designing for flexibility and reuse, on people-focused design, liveability, wellbeing and sustainable materials.

Globechain (top)
Materials passports provide information on the value of materials and products (bottom)

Materials passports provide information on the value of materials and products

Despite these advances, the built environment continues to face deep-seated challenges. The lack of transparency in the supply chain can mean that it is hard to know what materials a building contains and which of these can be reused, remanufactured or recycled.

Materials passports will help to tackle this by providing information on the value of materials and products, their reusable or toxic content and the ease with which they can be disassembled. The internet of things will be another important enabler of innovation. It could support the databases behind materials passports, for example, or help stakeholders find out how to reuse materials or share 3D models such as BIM. Transparency will also help the remanufacturing industry to calculate accurately the content and value of returned materials and products. This will save them time and money and promote reuse and resale on secondary markets.

Digital systems are creating significant efficiencies in the built environment. However, their potential to enhance how to understand, monitor and engage with environments is still in its infancy. Joining up digital technologies such as big data with circular economy principles offers opportunities to develop and promote new models of delivery and consumer engagement.

Arup's trial of smart desks called All About the Desk

At Arup we recently ran a trial of smart desks called All About the Desk. This has demonstrated the value of using digital technologies such as low-cost sensors and smartphones to give office workers greater control of their working environment. Smart technologies and open-source software allow staff to interact directly with adaptable and responsive heating and lighting systems, which are also easy to access and repair. The desks use renewable energy technologies and low-power voltage to limit their environmental impact.

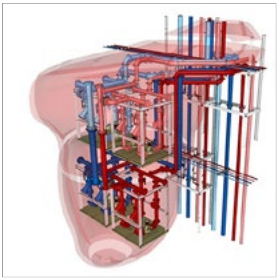
We have also worked with Sidewalk Labs, a subsidiary of Google parent company Alphabet, to develop technologies that unlock aspects of the sharing economy, circular economy and sustainable development. These include fully autonomous mobility, pervasive water collection infrastructure and local renewables with shared ownership models. Other technologies include recyclable modular buildings, digital services that enable shared resource loops, and new models for governance, health, security and privacy.

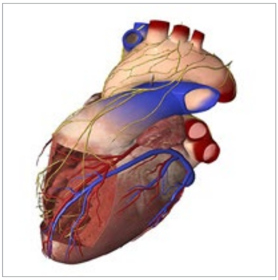
Advances in digital technologies and real-time data will increasingly underpin the services Arup offers its clients. Our ProjectOVE uses advanced BIM technology to create a fully functioning virtual building that replicates the human body. It employs collaborative design techniques and integrates interoperable software packages to show how BIM could transform the way that we design cities, buildings and systems to enhance performance throughout the lifecycle. We will continue to develop these skills and capabilities, testing and advancing them, while disseminating their impact and potential throughout the firm.

It's not only technological innovation that's required if the circular economy is to scale effectively. The financial sector has a role to play in providing new forms of capital flows or alternative earnings models that incentivise per-use approaches and spread cash flow over time.

Similarly, the legal sector should update contracts for the ownership and use of assets to ensure they are clear and secure. In the built environment, this could mean smaller, more frequent payments instead of lump sums. This would increase the residual value of assets designed for disassembly, and boost value creation in second-hand markets.

The cascading effect of these changes would require stakeholders throughout the value chain to articulate and apply new structures and methods. Communicating the benefits and providing assurances about the risks of these new approaches will help smooth this transition, as will collaborative partnerships between companies with the shared ambition to realise circular projects and initiatives.





ProjectOVE uses BIM to create a functioning virtual building that replicates the human body

5.4 Collaboration

"Delivering the circular economy requires a lot of collaboration and that's quite challenging. We need a system where every part is accruing value and that needs more trust between different partners through collaboration. We need economies of scale to make this work – it can't just be one company moving on their own".

—Dr Catherine Joce, Knowledge Transfer Network Limited

Complexity is one of the defining features of the built environment. Built environment assets tend to have long lifecycles in which multiple actors with diverging priorities and incentives interact and collaborate. Multiple stakeholders and long lead times also mean there is rarely continuity of ownership and control. Actors in the early stages of development (such as architects and designers) are rarely held fully accountable for outcomes further down the chain, such as the operation or end-of-life of an asset.

How can circular economy principles be embedded into this fragmented business model? It requires a collaborative approach to the development of industry-specific frameworks and principles, a shared vision and roadmap, and stakeholder engagement across the value chain. Collaboration and effective communication can align the various and often-conflicting elements of built environment projects – creating benefits for individual parties and the wider industry. Arup projects like A New House for London (see section 4) serve as valuable prototypes that show how collaborative working practices can cut costs, limit environmental impact and enhance resilience.

Although there are currently few strategic partnerships between stakeholders with aligned ambitions on the circular economy, promising examples are starting to emerge. One is a collaborative project facilitated by LAUNCH, a global platform that champions sustainability and innovation. Through this, IKEA is working with biomaterials company Ecovative to replace its polystyrene packaging with a mushroom-based alternative. This works by binding clean agricultural waste into a solid shape that can be dried, used and then returned to the soil through decomposition.

The LAUNCH project emphasises system-wide collaboration and encourages participants to discuss both their challenges and future priorities. This creates far-reaching disruptive change and builds communities around key challenges.

LAUNCH Nordic is a regional chapter of the network. It has created a private-public partnership that takes a collaborative approach to drive sustainable innovation in materials. This includes new business models, financial instruments, technologies, and programmes to accelerate research, education and capacity building.

Mushroom-based packaging (top) and IKEA (bottom)

Conclusion and Recommendations

"At the highest level of engagement we need to start a multi-stakeholder dialogue about mutual gains. The circular economy model can drive innovation and new ways of working; we see this as a way of rethinking design and redesigning thinking."
—Carol Lemmens, Arup

The circular economy model offers an alternative approach to growth. It uses fewer resources, lowers environmental impacts and relies less on volatile markets for natural resources. As well as being more sustainable, a circular economy can enhance resilience. It can create flexibility and additional capacity at a range of scales — individual assets, communities, cities or even whole economies.

The approach offers a compelling opportunity to tackle the complex and multi-dimensional nature of the built environment. It is a chance to enable a shift towards more sustainable forms of economic growth, urban life and value creation. Capitalising on this opportunity requires a move towards a systems-based approach that can be applied at the scale of buildings, neighbourhoods, cities, regions and entire economies.

Other than gradual efficiencies, the built environment has been slow to streamline its processes and adopt new technologies. Many of the old divisions and siloes continue to obstruct the kind of disruptive change that has transformed other industries.

But many of the principles associated with the circular economy in the built environment are not new. The industry has been maintaining, reutilising, upgrading and repurposing infrastructure and buildings for centuries. And new design approaches such as off-site construction are already well established.

Left: SolarLeaf House, Hamburg, Germany

What is missing is a specific built environment framework that binds all the existing and emerging principles and design approaches together. This needs to be a collaborative, all-encompassing framework that is defined not by the delivery of individual components, but by the circular functionality of the entire value chain.

Realising the potential of the circular economy requires a new approach to all aspects of the value chain. This includes financing, procurement, design, construction, operation, maintenance, repurpose and recycling. It requires a step change in systems thinking, design, technology and economic approaches. Connectivity and digitisation are helping to fuel innovation, which is driving a shift to circularity by maximising efficiency, encouraging flexibility and by cutting waste. A wholesale shift will necessitate the rethinking of the way the value chain operates, including business models, financial incentives, use of technology and rewards for reducing wastage.

The following steps and recommendations would help the built environment sector to develop and benefit from the circular economy.

Develop a circular economy vision and business models

- Define effective circular economy design frameworks and principles for the industry, together with a vision and roadmap to get there
- Analyse and develop new business models and services – including:
  – Alternative ownership models including leasing and performance models
  – Materials passports, profiles and flows into BIM and GIS models
  – Reuse and remanufacture, design for disassembly.
- Consult with clients wishing to implement new business models in the built environment supply and value chain
- Further investigate the challenges of finance and contractual arrangements – such as cash flow and job loss potential.

Collaborate

- Initiate collaborative activities such as industry and client workshops to help identify joint challenges, complementary expertise and opportunities for strategic partnerships
- Pre-competitive collaboration and strategic partnerships will help to articulate shared values and mutual gains
- Opportunities for partnerships with like-minded groups and organisations may also be identified through the Ellen MacArthur Foundation and CE100 network.
- Quantify and communicate the benefits
- Quantify direct monetary and wider socio-economic values and benefits (such as carbon savings or resilience) of circular projects and practices

- A database of costed projects illustrating the added value or cost savings within specific services (such as waste or materials) would help support the business case for clients and contractors considering circular initiatives
- Disseminate these examples through well-known industry channels, platforms and events.

Educate and raise awareness

- Familiarise staff, clients and partners with the language of the circular economy
- This will help them appreciate parallels with other subject areas (such as sustainability and resilience) and eventually shift mindsets towards more joined-up approaches
- Run staff training programmes to raise awareness across all grades and disciplines, and initiate targeted training sessions for leaders, project managers, and specific disciplines.

Develop case studies and examples

- Co-develop and share research that can challenge the industry to apply circular economy principles
- Share examples of circular approaches via networks such as CE100 and propose them in bids and discussions with relevant clients
- Initiate conversations with clients to encourage them to consider adopting circular principles in their projects
- Demonstrate the potential and value of digital technologies such as the internet of things through project examples, prototypes and pilots with partners.

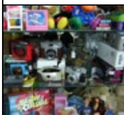
Innovate

- Encourage internal and industry innovation through competitions and demonstrations
- Implement pilots to enhance knowledge and skills, build capacity and drive innovation in the built environment
- Invest in developing advanced digital capabilities and test them on projects at different scales
- Explore and leverage funding opportunities to invest in research and development in the built environment sector.

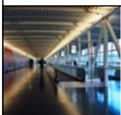
Appendix

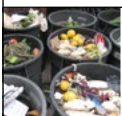
Summary of case studies featured in this publication, matched to the ReSOLVE framework.

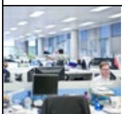
Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 Boxpark	✓	✓	✓	✓	✓	✓
 Arup's Madrid + Natural	✓		✓			✓
 Horizon Proteins	✓	✓				
 Nestlé Fawdon factory	✓	✓		✓		
 The Collective		✓	✓		✓	
 Airbnb		✓	✓		✓	
 WikiHouse		✓	✓	✓	✓	✓

Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 HeadBox		✓	✓		✓	
 Globechain		✓		✓	✓	
 White Collar Factory	✓		✓			✓
 3D Print Canal House			✓	✓	✓	✓
 HS2 Designing out Waste	✓	✓	✓	✓		
 DHL Reverse Logistics		✓	✓		✓	

Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 Caterpillar Remanu-facture			✓	✓		
 Tata Steel			✓	✓		✓
 Hong Kong sludge facility			✓		✓	✓
 Lync/Skype					✓	
 Forth Replacement Crossing			✓		✓	✓
 Sky Believe in Better Building	✓	✓	✓			✓
 Veolia bioplastics	✓			✓		✓

Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 Hy-Fi Tower	✓					✓
 SolarLeaf house	✓			✓		✓
 Additive Manufacturing			✓			✓
 Philips' 'pay per lux'		✓	✓		✓	✓
 A New House for London	✓		✓	✓	✓	✓
 The Circular Building		✓	✓	✓	✓	✓
 Peterborough Circular City		✓	✓	✓	✓	

Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 London: The circular economy capital		✓	✓	✓		
 Buiksloter-ham, Amsterdam		✓	✓	✓	✓	✓
 ReGen Villages, Amsterdam	✓	✓	✓		✓	✓
 Sharing City Seoul		✓	✓			
 Making Things Last, Scotland	✓		✓	✓		
 Food waste, France	✓	✓	✓	✓		
 Green Public Procurement, Denmark		✓	✓			✓

Project	Regenerate	Share	Optimise	Loop	Virtualise	Exchange
 Closing the loop - An EU Action Plan	✓	✓	✓	✓	✓	✓
 Chinese Association for the Circular Economy		✓	✓	✓		
 Reusing and recycling, Japan	✓	✓	✓	✓		
 All about the desk			✓		✓	✓
 Sidewalk Labs		✓			✓	✓
 ProjectOVE			✓		✓	✓
 LAUNCH		✓				✓

Further Reading

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Glossary

Anaerobic digestion (AD) involves the decomposition of organic material in the absence of oxygen using microorganisms, which generates biogas and a digestate.

Building Information Modelling (BIM) is an open-source digital 3D modelling tool that communicates information relating to all phases of an asset's lifecycle. It can be used by designers, contractors and building operators to plan, design, construct, and manage buildings and infrastructure.

Built environment comprises the man-made elements of our surroundings such as buildings as well as infrastructure including transportation, telecommunications, energy, water, and waste systems.

CE100 Network is the Ellen MacArthur Foundation's pre-competitive innovation programme established to enable organisations to develop new opportunities and realise their circular economy ambitions faster.

Circular economy aims to keep materials, components, products and assets at their highest utility and value at all times. In contrast to the 'take, make, use, dispose' linear model of production and consumption, material goods are designed and produced to be more durable, and to be repaired, refurbished, disassembled and reused in perpetuity - thereby minimising resource use, eliminating waste and reducing pollution.

Closed loop cycles are those in which nearly all materials remain within the system, and are recovered and used by other organisms or processes rather than being lost as waste.

Disruptive Innovation Festival (DIF) is an online, open access event that invites thought-leaders, entrepreneurs, innovators, businesses, designers and learners to explore the question "The economy is changing - what do I need to know, experience and do?"

ESCo (Energy Service Company) is a total energy supply service including the provision, financing, operation and maintenance of energy facilities. Energy services contracts may be worded to define the outcome of the service provided, temperatures and light levels, rather than how much energy is to be supplied.

Internet of Things (IoT) is a network of physical devices, vehicles, buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data

Materials passports provide information on the value of materials and products, their reusable or toxic content and the ease with which they can be disassembled. Information is collected in a database to facilitate the recovery, recycling and/or re-use of materials.

Negative externalities are the negative indirect costs suffered as a result of the production and consumption of goods. In the built environment these include carbon emissions and climate change, water, noise and air pollution as well as impacts on welfare, health, employment and social equality.

Net zero strategies promote the consumption of only as much energy or water as produced. The aim is to create a sustainable balance between resource availability and demand, and eliminate waste to landfill.

Resilience is the capacity of individuals and systems to withstand and adapt to occasional shocks such as flooding, terrorist attacks or ongoing stresses including increasing energy demand and lack of affordable housing.

Reverse logistics is a closed loop approach that uses remanufacturing, refurbishment, repair, reuse or recycling to recover and process materials and products after the point of consumption.

Servicisation is a model where a service, such as lighting or furniture, is offered instead of the sale of a product e.g. light bulbs or carpets. Ownership rests with the provider and performance based contracts are often used to ensure the provider delivers an agreed level of service.

Sharing economy is a collaborative consumption model focusing on providing users with access to goods and services via peer-to-peer exchange, online marketplaces and community-based networks.

Upcycling involves the reuse of a material or product to produce an item of higher value than the original

Zero waste is an approach that prioritises the reuse of all materials and products. This includes maximizing recycling, minimizing waste, reducing consumption, and designing for reuse, repair and recycling.

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12. Assumes a 22 inch pipeline, 10MtCO2/year, carbon steel, 330kg/m. Carbon steel cost assumed at £800/t. Scrap value is £160/t. http://www.sitechar-co2.eu/FileDownLoad.aspx?From=Faq&IdFile=317 and http://www.green-alliance.org.uk/resources/Circular%20economy%20Scotland.pdf
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Credits

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Authors

Rainer Zimmann
Resources and Waste

Harriet O'Brien
Energy, Cities and Climate Change

Josef Hargrave
Foresight + Research + Innovation

Marcus Morrell
Foresight + Research + Innovation

Graphic Design

Mark Pearsall
Foresight + Research + Innovation

Raphael Iruzun Martins
Foresight + Research + Innovation

Image procurement and clearance

Felicitas zu Dohna
Foresight + Research + Innovation

Nikki van Grimbergen
Foresight + Research + Innovation

Editor

Matt Blackbourn
Polon

Project Management

Marcus Morrell
Foresight + Research + Innovation

We would like to thank the following individuals for their contribution:

Josh Treuhaft
Foresight + Research + Innovation

Richard Boyd
Advanced Technology and Research

Kristian Steele
Advanced Technology and Research

ARUP

13 Fitzroy Street
London W1T 4BQ
arup.com
driversofchange.com