THE INDUSTRIAL RESOLUTION

New thinking on closed loop product design and manufacturing.

ARUP

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THE INDUSTRIAL RESOLUTION

New thinking on closed loop product design and manufacturing.

By Stephen Philips and contributors.
Forword by Sir Kenneth Grange.

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Sir Kenneth Grange CBE, PPFCSD, RDI
Industrial Designer. May, 2017

FOREWORD

Closed Loop Making – Sir Kenneth Grange

The raw materials we need to make the products we use, to construct the buildings we live in and the vehicles we travel in are not infinite.

Annually, around 70 billion tons[1] of material resources are extracted from the planet to cater for 7.3 billion[2] or so people who generate over 1.3billion tons of solid waste material.[3] We need to reduce the waste we create and reuse that waste as a raw material for new things. We need to make products, buildings and vehicles that are 'closed loop' that reuse waste material, last longer, allow repair and reuse and allow materials and parts harvesting at the end of their useful lives.

The decisions we make now and the initiatives we set in motion within the next few years will determine our children's and grandchildren's future. My call to politicians, industrialists, engineers, makers and designers of the immediate future is to penetrate this destructive cycle, based as it is on historic systems and processes and our limiting assumptions as to what we can expect the user to be capable of understanding, and begin to treat all products as a circular resource.

The issue today is not what we CAN do - which is the constant demand from commerce - but what we should do - to ease the human state. If closed loop making is to embrace more than recycling and economic making and secondary merits - such as economy in use - then it must engage intimately with the user.

The future, if we are to assert our trade as moral, caring and wholly beneficial should be one where design decisions are taken in a holistic way with multiple human and social benefits, long term and sustainable goals and a genuine engagement with and trust in the user.

THE INDUSTRIAL RESOLUTION

There is a growing awareness that the products and services we use should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment. This awareness raises numerous questions on what changes we need to make to achieve a future that is more sustainable. The questions around climate change and the environment are multi-layered and complex, covering many themes which are pertinent to people and the waste they generate. The Industrial Resolution offers insights and initiatives to show how the products we design, manufacture, use and dispose of can be designed and engineered to reduce the impact they have on our planet.

Arup is at the forefront of cutting edge architecture, engineering and design. Founded by Ove Arup and his colleagues in the mid twentieth century. Ove studied philosophy and engineering in Copenhagen, moving to London in 1923, setting up Arup in 1938. This foundation set Ove's course for social and cultural betterment through clever design and engineering and led to collaboration with some of the architectural pioneers of the 20th Century, including Jørn Utzon, Marcel Breuer and Arne Jacobson. Since these auspicious beginnings, Arup has grown organically, challenged by architects, designers, planners, artists and organisations globally to shape a plethora of innovative and inspiring building design, infrastructure and art projects.

As a wholly independent organisation Arup is owned in trust for the benefit of its employees and their dependants. With no shareholders or external investors, the firm is able to independently determine its own priorities to shape a better world. This includes investment in research, innovation and development activities. The Industrial Resolution is the result of our global research, design and development activities in the field of product, building and vehicle design. This, combined with knowledge harvested from our globally distributed specialists in materials, sustainability, human factors, waste, transport and buildings, demonstrates strategies and real examples of how we can direct our knowledge, resources and enthusiasm into products that are closed loop.

Image: **The Al Bahr towers**, designed by Aedas and engineered by Arup are over-clad on the south, west and east elevations by a unique dynamic shading system that opens and closes to provide self-shading as the sun moves around the building.

ARUP AND OUR JOURNEY INTO PRODUCT DESIGN

Arup's work in the realm of product design has grown during the past decade from our multi-disciplinary design and engineering roots.

The team consists of an imaginative and dedicated group of individuals harnessing Arup's global technical and engineering expertise to develop designs that resolve user and our clients' needs. Each project is a response to a particular challenge requiring a tailored approach and design process. From the outset, a product's form and function are rightly treated with equal importance. We involve our clients and users as much as possible in the design process. The design projects we work on are intentionally diverse and encompass a realm of mechanical and electronic appliances, furniture, digital devices, lighting, building products and components, transportation and packaging.

Image: Stephen Philips working on the View LED lighting range.

Like many other designers, we are in a privileged position to influence people and the products they use in their everyday lives. It carries a responsibility to do the best possible job for current society and ensure our work leaves a significant and positive legacy for subsequent generations.

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Putting sustainability at the heart of our projects is one of the ways we make a positive influence on the wider world. Investing in research and development is another; without such investment, innovation can be stifled. Without the capacity and freedom to innovate, our ability to combat the effects of climate change and other global issues would be compromised. ‘The Industrial Resolution’ reveals just some of the inventive and fascinating approaches we have initiated and encountered, drawing on the work of international designers, engineers, industrial and commercial organisations. These case studies capture diverse insights and approaches to the subject of product sustainability at this moment in time. The product landscape is extremely diverse because they respond to different problems, wrapped up in the history and culture of the people that make and use them. In my view, climate change in the product world won’t necessarily be resolved with sweeping, radical change but will need to be addressed incrementally by a number of different approaches that are appropriate to the circumstances of the particular product and the people that make and use them. To encourage an approach and policy that reduces waste and use of dwindling resource will be a key driver as more often than not, taking a more sustainable approach can be less convenient and therefore more expensive than buying products which are cheap to make, easy to source, buy and dispose of…the roots of the disposable culture.

I joined Arup in 2008, a product and furniture designer, excited by the opportunity to work with some of the world’s leading technical specialists. Familiar with Arup’s significance in the world of architecture and infrastructure design, developing a product design team at Arup continues to be an exciting and intriguing opportunity.

Although products aren’t buildings (buildings are larger, more permanent and almost always prototypes), the products we work on are still imbued with cultural, human and performance factors that are vital to the success and significance of some functional products over others. They also have to work and specialist input from our technical staff ensures that form and function work hand in hand. Products have fewer parts than buildings, often designed for serial production, assembly and efficient distribution. Our engineering colleagues enjoy applying their knowledge and skills on products, useful physical objects of a different scale.

Images: **Craft LED Hi Bay lighting** installed at Comer Industries factory near Milan. Lighting manufacturer Zumtobel now offers light as a service, taking responsibility for luminaire refurbishment, upgrades and recycling at end of life; **Pocket Habitat modular green roof product**, designed by Arup for Sky Garden; **Arup's Product Design team.**


CRAFTSMAN
NICKEL PLATED

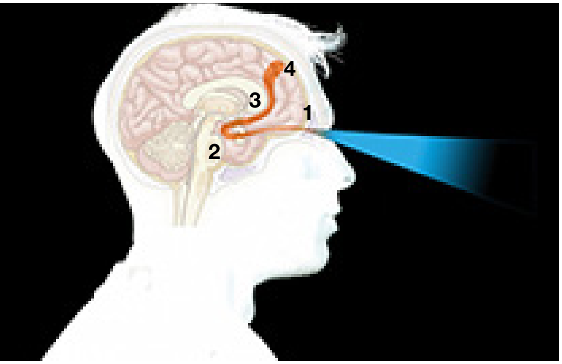
AESTHETICS

AND THE DEVELOPMENT OF TOOLS

The first stone cutting tools were made and used by Australopithecus afarensis in East Africa some 3.3 million years ago.[4] During the next 3 million years Homo Habilus and Homo Erectus made small refinements to the tool's designs and grew their tool repertoire for different purposes such as chopping and spearing. This allowed them to thrive in their immediate environment and migrate. It wasn't until the arrival of Neanderthals, just 33,000 years ago that there was a significant change and flowering of creativity with the development of imaginative ornamentation and jewellery. Since then objects and tools have become as much about how they look as how they work. During the industrial revolution, new tools and objects were invented, refined and optimised for industrial production. We can start to think of these items as 'products', standardised and useful tools, mass-produced and traded on a large scale.

In the 20th century Modernist designers believed that good design was about usefulness – how well an object performed its function. For others, good design is less tangible. It might be something that is capable of provoking an emotional response- perhaps through beauty or wonder. It's clear that what is good design is open to debate and interpretation. Many people share the belief that there is a moral or ethical component to design and that design can be responsible for enriching our lives or 'doing good' in the world. However, if good design can improve our world then presumably bad design can harm it. This highlights the moral responsibilities of designers and of the people who use their creations.

Through history, useful objects have been imbued with cultural references and an aesthetic, non-functional element or shape to the design that go beyond mere usefulness. Our understanding of human psychology, anthropology and the mind has developed tremendously during the past century. This, combined with more recent investigation into behavioural neuroscience, or the process mechanisms within the brain are helping us to realise the importance of people's perception and experience of certain products, object shapes, materials and the meaning behind them. We have a growing understanding of the importance of working with, not against people's expectations of what a product should look like as well as how it works.



It is now widely accepted that people need to experience excitement, pleasure and confidence when looking at and appraising a product or thing for the first time. These experiences vary from person to person, but an experienced designer can shape products to achieve these positive responses. They happen subconsciously within a few seconds or so of encountering a new product. It is only after this, once the person has experienced their 'first impression' of the product or thing will they consider the performance and value of the product. This process can be linked to the neurological processes within the central nervous system.

When viewing an object or thing, the optic nerve sends a nerve impulse from the retina to the amygdala in the brain. The amygdala reacts quickly and emotionally to the object…a reaction of excitement and pleasure or disinterest and at worst fear. A secondary, instantaneous impulse from the amygdala deep in the centre of the brain to the cingulate gyrus in the front of the brain, informs our secondary cognitive reaction to the product or object, based on our past experiences. This can explain why people feel comfortable with certain product characteristics and shapes and less comfortable with others. For instance, users understand that chairs made from wood, with four legs work, whereas a seat made of sheet glass induces fear as a user is familiar with the cold brittleness of glass and the harm it causes if it were to break. Finally, our dorsolateral prefrontal cortex, the front of the brain responsible for analytical thinking or logic, helps us to consider product performance and price.

This understanding shows that although product performance is an essential part of the product make up, the product's shape or 'look and feel' needs careful consideration. It is less acceptable to make a product that looks great but doesn't work and there is equally little excuse for making a product that works well but looks wrong for its application and uses slightly inappropriate materials as no-one will feel compelled or confident about purchasing it in the first place. This premise helps us to understand the approach required for products that are more in tune with people's psychological and functional needs and therefore more sustainable and less wasteful. It also explains why people are unlikely to buy and use a product where its sustainability credentials are the main feature. The product has to look right, work beautifully and offer value as well.

This understanding shows that although product performance is an essential part of the product make up, the product's shape or 'look and feel' needs careful consideration.

Images left and above:
Minoan pottery from Pyrgos, Greece 3000–2600 BC; **Our reaction impulse** to seeing things.1: Retina; 2: Amygdala; 3: Cingulate gyrus; 4: Dorsolateral prefrontal cortex; **Ray Eames** sitting on an experimental lounge chair, 1946; **Model T Ford** assembly line, 1913 Detroit.

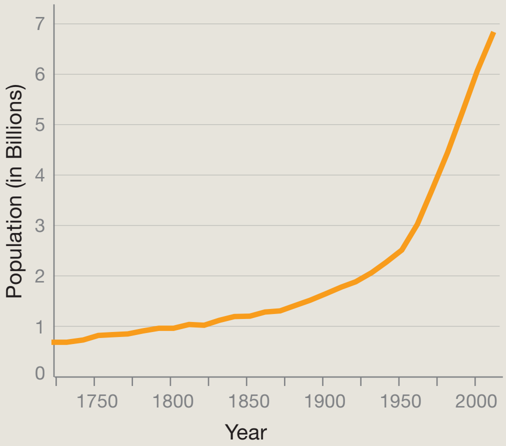
Designers, engineers and manufacturers need to consider how they reuse recycled materials in new products and consider how the materials can be separated and recycled again at the end of that products useful life. Many of the most successful, useful things that we use today are the result of evolutionary design, the seeds of which were developed by our ancestors. To understand the context of why products are the way they are today, we can study how things were made and used in the past.

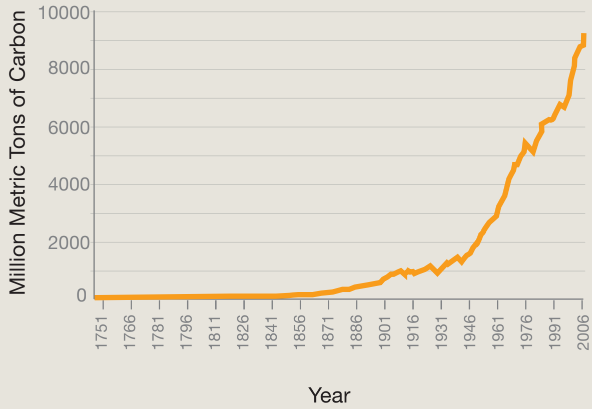
THE INDUSTRIAL REVOLUTION

In the developing world, there were rapid changes in technology, farming, mining, manufacturing, and transportation from the mid-18th to mid-19th Century. These technologies had an impact on people's social and cultural life, as well as their economic conditions. Machines such as the steam engine were developed and used to power machinery that could perform many of the jobs and tasks that had previously been carried out manually. Before the Industrial Revolution, societies were largely rural. Industrialization meant that more and more people lived in towns and cities where goods were increasingly mass produced in purpose-built factories. A network of roads, railways and canals, that allowed people and goods to be transported, grew in parallel.

This transformation brought about better economic conditions for many people. Before the Industrial Revolution, each generation produced a roughly similar number of utilitarian objects to their predecessors and overall economic conditions were relatively stagnant. After industrialization, production grew year on year and the capitalist economic system resulted in human prosperity, comfort and certainty for some, as well as poverty and hardship for others. Waste, pollution and carbon emissions also grew. The steam engine was one of the most important inventions of

Image: A replica of Thomas Newcomen's 1712 steam engine, used to pump water out of tin and coal mines during the industrial revolution.





the Industrial Revolution. The first practical steam engine was a machine made to pump water out of mines by the English inventor, Thomas Newcomen in 1712. The design was later improved upon by the Scotsman, James Watt. As well as powering the machines used in factories and mines, steam engines were also used in ships and locomotives, improving the transportation of people and goods dramatically. Naturally, the quantity of manufactured goods increased to meet the needs of a burgeoning population. Our global population reached approximately 1 billion in 1800 and increased to 1.7 billion in 1900 [5]. The past 118 years has seen the world's population expanding by 440% to the 7.5 billion estimate we see today.

The Industrial Revolution was an inevitable and necessary turning point for the developing world, but more than ever, the consequences of this revolution now requires change, a closed loop approach to design and manufacturing. Having reflected on the history and challenges facing designers and the society they serve we have identified a number of key projects and initiatives which represent that incremental change towards Closed Loop Design. Some of these are small scale and localised while others have the potential to scale up and become global systems.

Images above: **Global population and CO2 emissions** between the mid 18th and early 21st centuries

THE CIRCULAR BUILDING

CAROLINA BARTRAM

Introduction

The Circular Building was an exploration by Arup, Frener & Reifer, BAM and the Built Environment Trust of circular economy principles in the construction industry inspired by the fact that our industry produces three times more waste than UK households. It was intended to test the maturity of circular economy thinking in the supply chain and to examine what it means for building design. The aim was to design and build a small prototype building for the 2016 London Design Festival. The challenge was: *Can we design a building which is flexible in its use and, at the end of its life, all its components and materials are reused, re-manufactured or re-cycled?* We found that asking this question profoundly altered the design and construction priorities.

Images: The Circular House. Image: © Ben Blossom.

Design Frameworks

The team used two frameworks to develop their ideas. The first is the ReSOLVE framework defined by the McKinsey Centre for Business and Environment with the Ellen MacArthur Foundation. This framework identifies six ways of implementing circular economy principles: Regenerate, Share, Optimise, Loop Virtualise and Exchange.

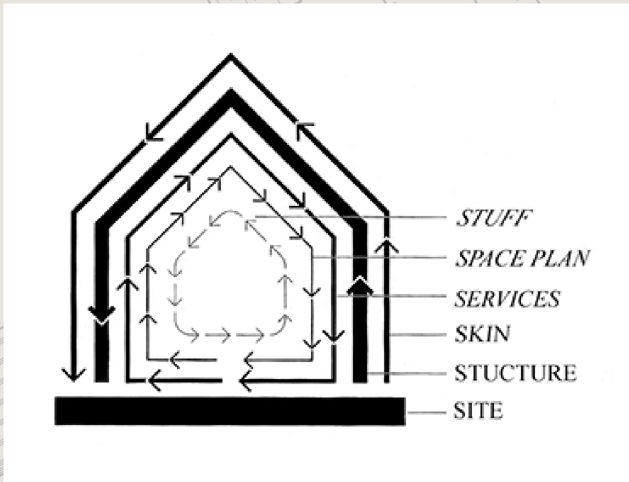
We also categorised the building into six areas defined by their likely life in a "typical" building. For this we used the categories set by Stewart Brand in his book "How Buildings Learn". These are: Site (long term), Structure (50-100 years), Skin (15-20 years), Services (5-15 years), Space (i.e. space planning 5 years) and Stuff - all the other things inside such as fittings and furniture and our belongings (short term). Using these categories helped shape our discussions during the design stages and in fact the building became a physical incarnation of Brand's diagram.

Images over page: Diagram from Stuart Brands book "How Buildings Learn"; **The** Circular Building; **Cladding** sketches

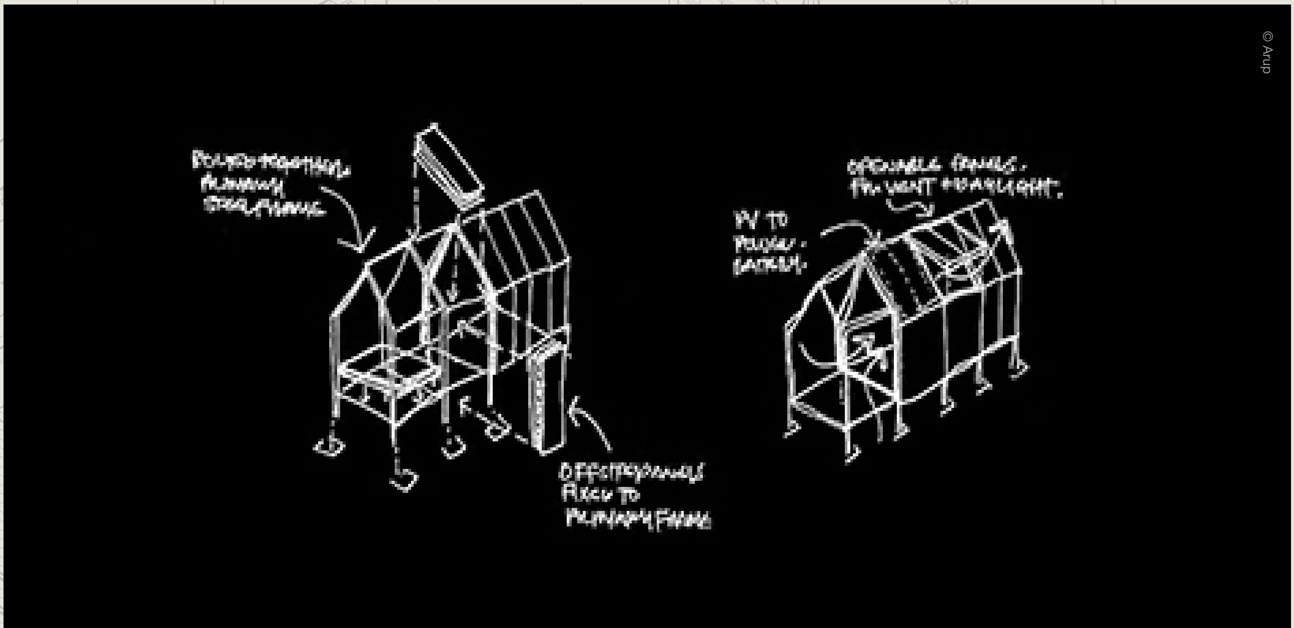
Design Principles

Early discussions were focussed around space planning and structure which are the two elements of a building which tend to define its overall life. We were keen that the Circular Building, although small and with a defined lifespan, explored principles that were more universally applicable to larger scale, more permanent building typologies. In particular with regards to structure there was a lot of debate about the balance between providing flexibility and ensuring longevity of use, against designing for deconstruction. Currently when most buildings are demolished the structure is down-cycled: concrete waste is used to form engineering fill for roads and landscapes or aggregate for new concrete structures, timber is used as fuel for biomass plants, and steel is melted down and reformed. So, ensuring the longevity of a typical structure is possibly the most important issue in terms of keeping materials at their highest value for the longest period possible.

REGENERATE	• Shift to renewable energy and materials • Reclaim, retain and restore health of ecosystems • Return recovered biological resources to the biosphere
SHARE	• Share assets (eg cars, rooms, appliances) • Reuse/secondhand • Prolong life through maintenance, design for durability, upgradability etc
OPTIMISE	• Increase peformance/efficiency of product • Remove waste in production and supply chain • Leverage big data, automation, remote sensing and steering
LOOP	• Remanufacture products or components • Recycle material • Digest anaerobically • Extract biochemicals from organic waste
VIRTUALISE	• Dematerialise directly (eg books, CDs, DVDs, travel) • Dematerialise indirectly (eg online shopping)
EXCHANGE	• Replace old with advanced non-renewable materials • Apply new technologies (eg 3D printing) • Choose new product/service (eg multimodal transport)


STUFF
SPACE PLAN
SERVICES
SKIN
STUCTURE
SITE


© Ben Blossom


© Arup

Design for Longevity

What "design for longevity" means for buildings is highly debatable. It is not always the buildings that are designed for longevity that last longest, as shown by the famous example of MIT's Building 20; which was built as a temporary timber shed during the war and survived until the late 1990's. This unassuming building was the laboratory of choice for 9 Nobel prize winners, Naom Chomsky's linguistics laboratory and innumerable tech start-ups despite being cold, leaky and "implacably ugly"[6].

A recent study by Arup engineer Helene Gosden into the current trend for adaptive reuse of commercial office spaces found ten key indicators of whether a building was suitable for re use. Increasingly the list was split between design issues (loading capacity, plan layouts) and pragmatic issues (records, drawings, information).

For building structures, a key consideration is the balance between allowing for potential future higher loads and the capacity for creating openings and removing elements, against the requirements for lean construction. In the design of the Circular Building we ended up with the idea of a singular space with a repetitive structure that could be partitioned up internally or extended in length.

Design for Deconstruction

Design for deconstruction of a structure is also a key issue with regards to the circular economy, but currently the economic argument for carefully taking apart a building and reusing the materials rarely equates.

This is due to a complex range of issues. On the one hand, we do not have a market in terms of reused materials -partly due to lack of traceability in terms of quality and performance of the materials. Many of the buildings where we have considered reuse of structural elements have reused the steel or timber on the same site and in those cases the cost of careful deconstruction and testing have had negligible economic advantage over the more standard route of demolishing and selling materials for salvage.

Another important issue is that, outside of housing or warehouse/shed type structures, most buildings are tailored to suit their site and brief, rather than being repetitive "products" like cars. This means that the use of standardised prefabricated systems, which would lend themselves to deconstruction, do not always lend themselves to many of the buildings we design without some element of customisation.

Inportance	Building Attribute
1	Condition of existing structural frame
2	Availability of archive information
3	Existing floor to ceiling heights
4	Party wall issues
5	Depth of building
= 6	Internal space layout / Historic listing
8	Building structure (type of frame)
9	Load capacity
= 10	Structural redundancy / Foundations

The final argument against design for deconstruction is that typically ‘cast in place’ concrete, often reinforced with steel rebar or mesh, is the preferred material, used for floors and foundation construction for many structures, in terms of both economics and robustness. This form of construction provides a high level of strength, fire and acoustic resilience that is simple and cost effective to build. Unfortunately, full deconstruction and reuse of this composite material is virtually impossible. Concrete’s mix of chalk and clay cement, sand, gravel and crushed stone aggregate mixed with water results in a consolidated mass that can only be dismantled through demolition. This, coupled with a cast in steel rebar skeleton within the structure makes harvesting the concrete and steel even more difficult and expensive. Challenging this both in terms of the use of different materials, but also in the way we use concrete is something many engineers are looking at.

Design for deconstruction of structure is something that we are looking at more often, but currently the economic argument for carefully taking apart and reusing materials is not there.

Image:
Reinforced cast concrete

Notwithstanding these arguments we felt that as an exemplar structure the Circular Building had to attempt to be a fully de-constructible building for all components, not just structure. This meant considering, from the beginning of the concept design stage, not just how we would erect and install the various elements, but also how we would take them down with minimal impact to the component itself and what we would do with each element at the end of the project. This meant that it was critical to engage with contractors and suppliers from the beginning to understand what they might take back, and under what conditions, or whether we could lease or hire components.

We decided to use steel for the main frame as it lends itself towards a design for deconstruction methodology but we worked with the fabricator and supplier to develop details that minimised any customization. For example, we used end plate connections as cutting them back minimally had less impact on the rest of the steel member. We also tried to avoid any holes or fixings into the steel structure for secondary connections to facades and finishes. Instead we worked with Lindapter to develop clamp fixings that would connect effectively and resist the loads required. The floors were timber with minimal glues or fixings.

The project also challenged us to re- think the way we design façade systems nowadays. Prefabrication as applied to facades often means glued, pre-sealed or unitised panels – but we began to question whether this was the best way forward or should we be making facades which could be deconstructed into their components. So, we created a simple clamped glazed façade, rather than a glued system and used more high-tech approaches to maintain a dry air cavity, rather than sealing the panel irreversibly. This form of construction would have the advantage of allowing the components of the facades to be upgraded over the years or to be deconstructed and re-cut to size for a new use.

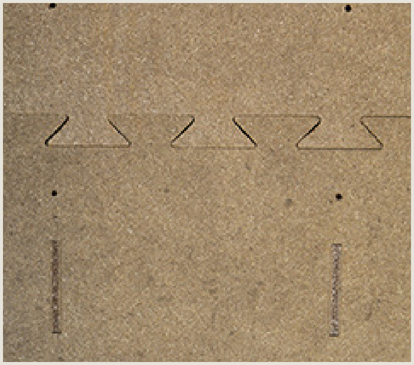
We also used open source, push fit techniques and patterning for the backing panels of the solid facades.

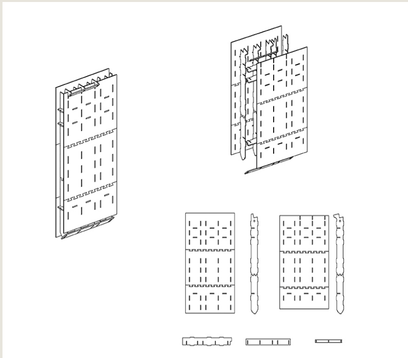
We used a base particle board made from waste timber and designed the panels to be lifted and slotted together without mechanical fixings. This was less successful than the steel frame or the glazing as we realised that the variances we could get with CNC cutting the particle board were greater than our push fit tolerances, which led to some last-minute filing down on site as well as some last-minute screw fixing. The contractor was also distinctly nervous of a system without positive fixings.

However, the greatest challenge in terms of facades was in finding a membrane which was not bonded in place. We finally found a system which was mechanically fixed. Overlaps in the waterproof membrane were glued together to form a seal but could be cut and re–bonded at least once or twice.

The project also challenged us to re-think the way we design façade systems nowadays.

Images over page clockwise: **Cladding panels** and structural steel with bolt connections; **Particleboard interior panels** with push-fit connections; **Lindapter clamp fixings** allow disassembly and seperation of materials; **Cladding panel** assembly drawings.





Materials and Sustainability

The previous examples were primarily concerned with methods of construction but we also did a great deal of research into individual materials and products.

A key consideration was what would happen to the materials and systems at the end of the Circular Buildings life. Would they go back to suppliers? Could they be re-fabricated? Could they be sensibly recycled or did they fit within a cradle-to-cradle system? The cradle-to-cradle approach to design was developed by William McDonough and Michael Braungart in 2002. It is a method used to minimize the environmental impact of products by employing sustainable production, operation, and disposal practices and aims to incorporate social responsibility into product development.

Under the cradle-to-cradle philosophy, products are evaluated for sustainability and efficiency in manufacturing processes, material properties, and toxicity as well as potential to reuse materials through recycling or composting. Many of the materials we worked with were designed to go back to the fabricators if the Circular Building was not re-built somewhere else.

© Daniel Imade, Arup

This was enabled by the short-term nature of our project, however in reality only the suppliers of a few products, such as the Accoya cladding and the Desso carpet, were set up to take back their product.

We also used a high proportion of materials recycled from waste products, such as Kvadrat's Revive upholstery fabric, made from 100% recycled polyester which can in turn be recycled.

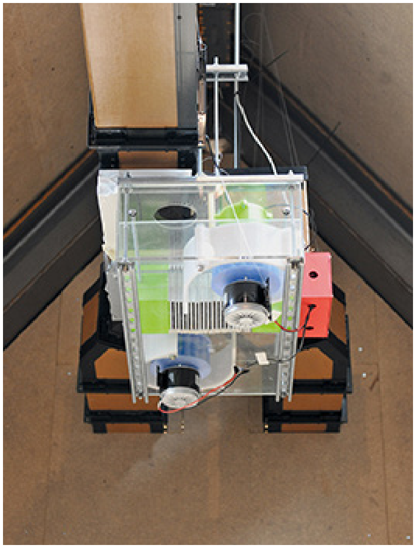
Materials and products were reviewed to find the best balance of efficiency and circularity. A prime example of this was the cradle-to-cradle certified Aquion salt water battery where every part was made from abundant non-toxic materials capable of being recycled.

Energy and Sustainability

It is fundamental to circular economy principles that the building was designed to be low energy, to consume minimum resources and to recycle heat and water where appropriate. The wall panels were highly insulated and air tight to better than current UK Part L building envelope requirements to prevent heat loss in winter and heat gain in summer.

The mechanical ventilation heat recovery (MVHR) unit provided a novel low energy ventilation solution maintaining high levels of fresh air with limited energy use, particularly useful for winter. The electrical installation used a low energy, low voltage direct current (DC) system which is safe and inherently flexible for building owners to adapt to the future needs. The light fittings were controlled using Bluetooth low-energy (BLE) technology, removing the need for separate control boxes. All the services were controlled using an open source central processing unit which allowed for future flexibility. The roof was designed to support modular photovoltaic (PV) panels which can be linked to the low pollutant salt water ion based Aquaeon battery.

In the Circular Building, the services design prioritised the circular principle of flexibility to allow upgrading and reuse to extend the life of the building and systems within. The Mechanical Ventilation with Heat Recovery Unit (MHVR) was designed and built by Federico Casarini and a team of Arup staff using recycled plastic, aluminium cans and a refurbished electric scooter motor. The casing and heat exchanger elements are recyclable. The lighting installation reused components from previous Arup exhibitions and installations which will be used again in the future.



It is fundamental to circular economy principles that the building was designed to be low energy, to consume minimum resources and to recycle heat and water where appropriate.

Images left and above: **The Circular Building's** external cladding and photovoltaic panels; **The Mechanical Ventilation Unit** made from re-purposed components.

Waste is Material Without Information

The final area we investigated was the link between information and circularity. What was clear was that no matter what we did with the design and construction, if the ideas and essential information could not be handed on then they could potentially have minimal impact on the future reuse of the building. The economic and practical argument for reuse has to be based on a having a good material and information database; whether this is with regards to the materials and design of a building or whether it helps source what is available on the market.

Building Information Modelling (BIM)

In terms of building design, we realised that we need to have a good set of information for all the building components, stating what they were, the properties that were key to their reuse, where they came from, any issues that might affect their reuse (for instance fatigue loading on structures) and how we envisaged their deconstruction. Alongside this information other physical stamping or certification is useful to guarantee certain fundamental issues, such as material strength. Steel structures are now physically CE marked on site. This helps confirm the grade and physical properties of the steel but as it is usually a small scale mark its use is limited to validation.

For the circular building, we had a full Building Information Modelling (BIM) model which contained information on all components including a materials passport and details of key issues. BIM models can now be linked to give “X-ray” views of the buildings. This means you can stand in a space and using a simple tablet view the hidden build-up of the space, which would be a great help in understanding the potential of reusing a building.

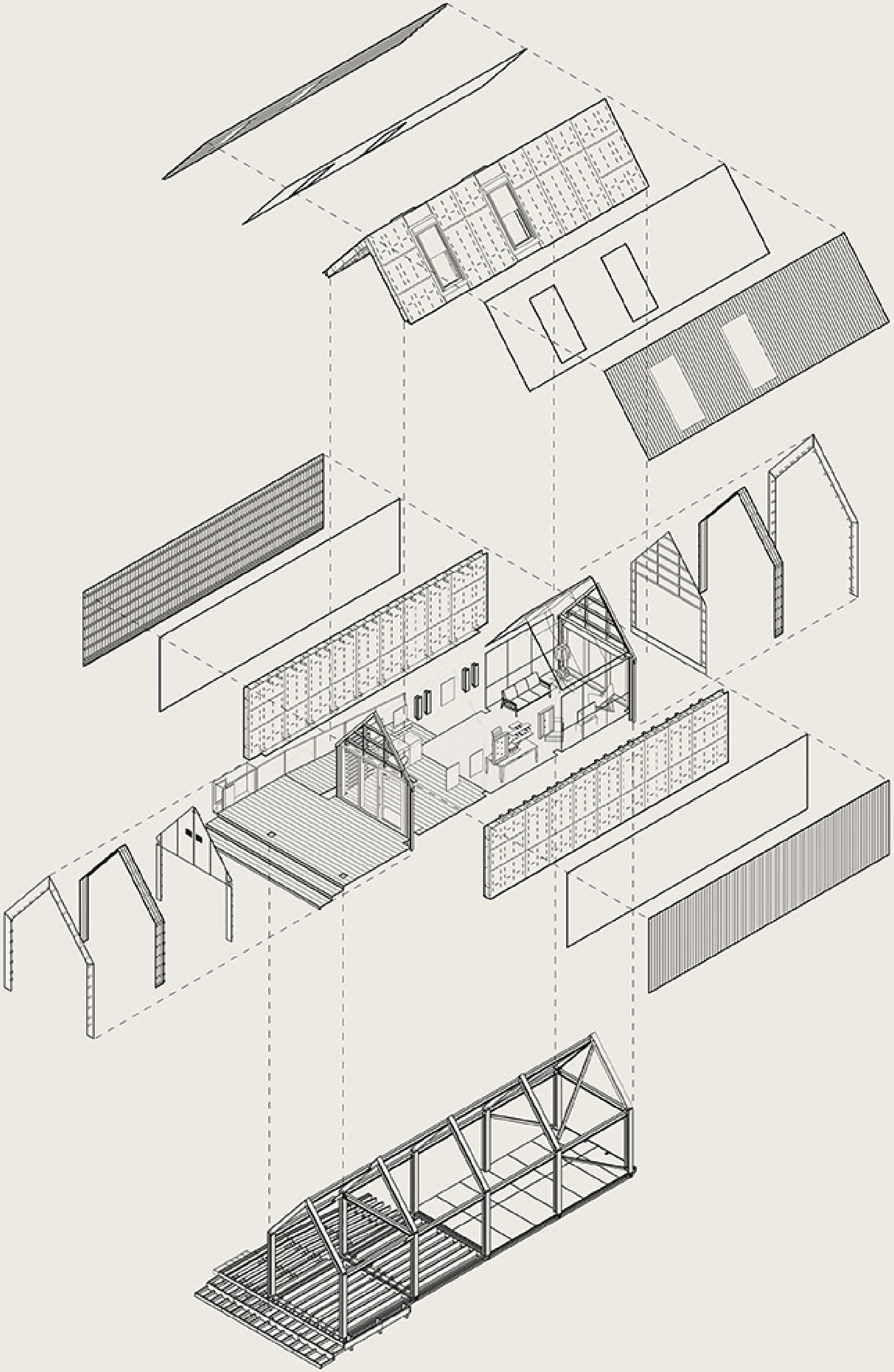
The materials data base was also linked via Quick Response (QR) codes to each element. So simply pointing a QR scanner (easily downloadable to a smartphone) provided a link back to the website hosting the data base.

Markets and databases of secondary materials should have become more accessible but in reality, the few suppliers we spoke to felt that the market had actually shrunk over the last few years.

The best examples we found were where companies could come and remove a particular element and reuse this material almost directly (gypsum ceilings being one example). For structures with a long life, set against the rate of change of material technologies, the use of secondary materials may be less achievable, for instance the increasing strength of standard steel alloys over the last 30 years may mean that older materials are no longer usable. Also, the time between design and construction, often up to a year or more for large structures, means that it’s difficult to foresee what elements may be able to come from secondary stock in advance. We need a different and more flexible design process if we are to engage with the circular economy.

I have only touched on what feels like a few aspects and materials that we used on the Circular Building. There were also discussions and research into finishes, furniture, environmental systems, renewable energy, batteries etc. that would take a book to cover.

The project was fast and furious but was a great learning experience for the whole team. It enabled us to try out ways of designing and building and to test the use of certain materials and typologies, which we could not have done in a more commercial project. However, this work is now feeding back into our more mainstream projects. Clients, designers and contractors are asking about how a Circular Economy could benefit their projects and this build was invaluable in helping us to explore this.



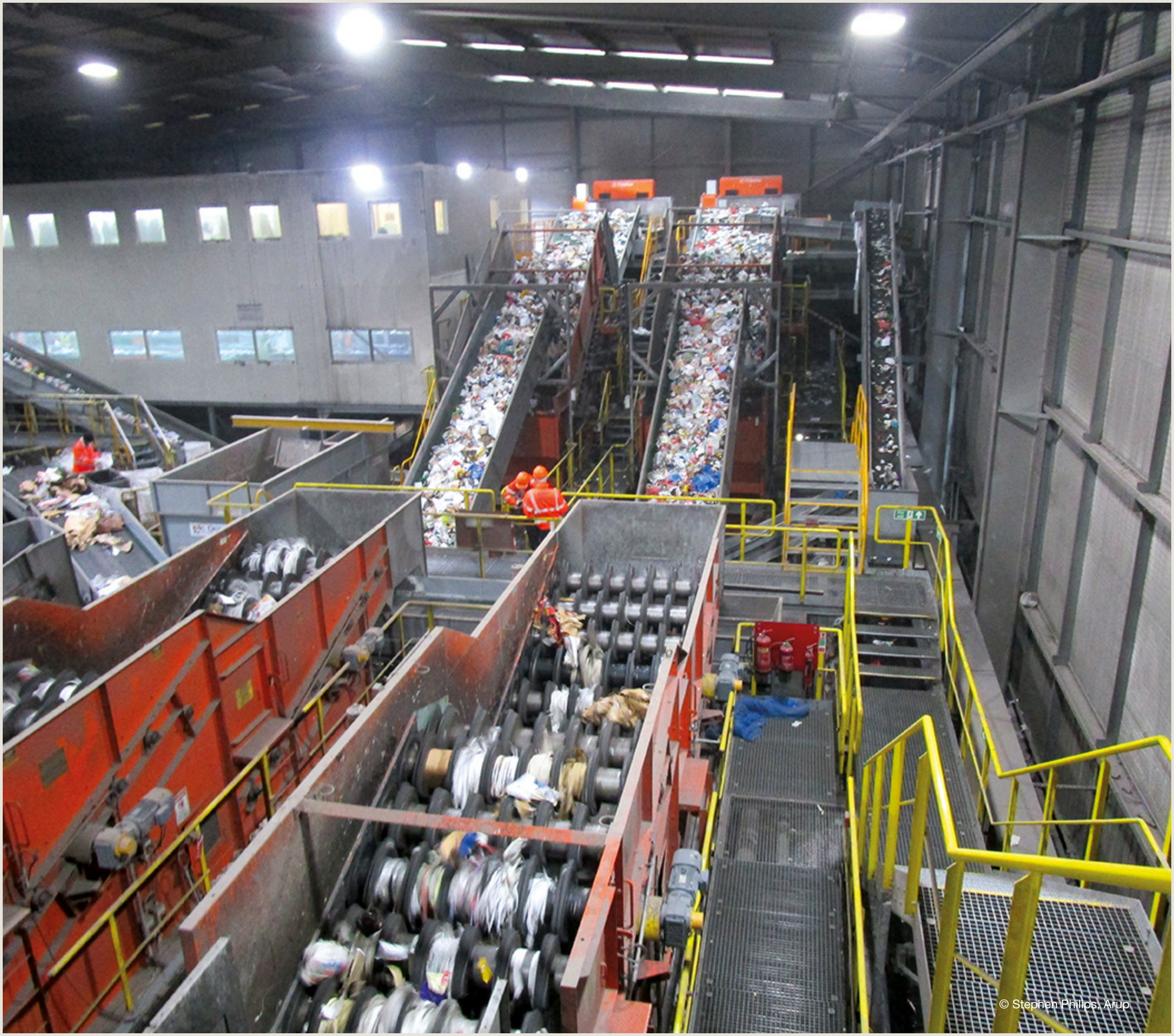
Images above: **Exploded** assembly drawing **The** Circular House; **QR Codes** with links to material and product suppliers websites.

CONVERTING WASTE INTO GOLD

THE ART OF UPCYCLING

The Crown Estate is the collection of land and holdings in the UK belonging to the British Monarchy making it the ‘Sovereign’s public estate’, which is neither government property nor part of the monarch’s private estate. The Estate’s property portfolio includes buildings on Regent Street and around half of St James’s in the heart of London’s West End.

Image: Regent Street © Dreamstime


© Stephen Phillips, Arup

Their tenants include retailers, restaurants, hotels and coffee shops at street level, with offices located above. It returns 100% of its annual profits to the Treasury for the benefit of the public finances. This has totalled £2.6 billion over the last ten years[7]. In 2002 The Crown Estate started a £1 billion investment programme to improve Regent Street's commercial, retail and visitor facilities and public realm. The initiative has delivered an international retail destination with world-class new buildings, wider pavements, new public realm, beautiful lighting, great restaurants and leading retail brands.

In 2017, The Crown Estate commissioned a scoping study from Arup to find ways to upcycle Regent Street's tenants' operational waste, specifically 'mixed recyclables', the intention being to reduce waste output and gain more value from it. The project forms part of The Crown Estate's ambition to eliminate waste from across its Central London portfolio by 2030. Positive social outcomes from the project would be of added benefit. The waste resource was to be taken through closed loop recycling and making strategies and returned to the Regent Street tenants for reuse. Conversion and manufacturing processes had to be considered including the wider supply chain involved in the production of the new products. The idea of upcycling is to reuse waste material and transform it into something useful and more valuable.

Material Selection and Design Approach

Arup's product design team set about collecting examples of the operational dry waste from the Regent Street consolidation centres where the different waste streams are collected ready for delivery back to London's state of the art Material Recovery Facilities (MRF's). The waste paper from offices and paper cups from coffee shops, cardboard and plastic packaging from retailers, as well as used wine and beer glass bottles from restaurants and hotels were to be used as the new material resource. The team worked with the client, MRF's Bywaters and Paper Round as well as Arup London's materials and waste specialists to come up with product design and closed loop initiatives.

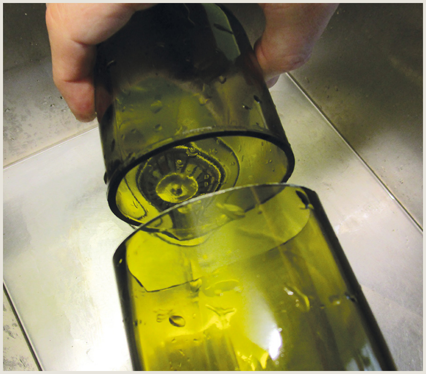
As well as designing products that reuse the waste, the team proposed the development of upcycled manufacturing, reuse and logistics initiatives necessary to sustain the upcycling concepts they developed.

The proposals included new office furniture and packaging and paper manufactured from waste paper and cardboard pulp, re-usable coffee cups designed to reduce the need for non-recyclable laminated coffee cups and glass tumblers and mini desk gardens and planters made from the large volume of waste bottles, designed for reuse in the restaurants and offices. Packaging could be converted into re-usable lunch boxes designed to reduce reliance on 'use-once' food packaging waste that was so prevalent in the waste stream.

Image Left and right:
Bywaters Materials Recovery Facility in East London; **Waste upcycling workshop** © Stephen Philips, Arup

UPCYCLING WINE BOTTLES INTO GLASS PRODUCTS

Glass bottle to tumbler upcycling process




Coke
Coke

The Upcycler - Goldfinger Factory

One of the upcycling concepts has been quickly realised into a commercial operation. The team had developed a range of design concepts and initiatives also investigating who could carry out the upcycling material conversion process. As part of their comprehensive investigation, they identified Goldfinger Factory, an award-winning design, making and teaching platform with a focus on upcycling that creates bespoke furniture and interiors, whilst helping artisans and artisans-in-the-making become self-sustaining, saving materials from landfill and providing skills training to assist people in gaining or returning to employment.

On meeting the Goldfinger Factory founders, Oliver Waddington Ball and Marie Cudennec, Arup's team found their enthusiasm and commitment to design, upcycling and social enterprise infectious. As a result of their collaboration, they recently developed one of Arup's initial design concepts into 'Golborne', a family of small, medium and large storage and desk tidy products that combine waste, blow moulded polyethylene milk bottles from offices and coffee shops with waste timber from interior refurbishment projects.

The materials are converted into products carefully, with minimum energy use and transportation costs. The waste resource nature of these products is intentionally non-explicit. The food safe, blow moulded polyethylene containers have a soft, translucent quality that appears modern and contemporary. The cut solid timber lids add weight, warmth and character. All the components can be separated and replaced or recycled at the end of the products usable lifespan.

Images above:
The Goldfinger team; **Stephen** Philips with Oliver Waddington Ball © Paul Carstairs, Arup

Images: © Daniel Imade, Arup

As a result of their collaboration, they developed 'GOLBORNE', a family of small, medium and large storage and desk tidy products that combine waste, blow moulded polyethylene milk bottles with waste timber from interior refurbishment projects.

Stephen Philips who came up with the new design and logistics concept stated. *'We can't assume people will buy products on the basis they are sustainable, the look, feel and function of the design and the story behind it has to stack up. The GOLBORNE range offers a sustainable approach to the manufacture of functional and beautiful products, one that uses waste as a resource with minimum impact, whilst providing less advantaged people with the know how to make a living from upcycling in the future.'*

The waste material harvesting and conversion process is relatively simple. At the end of each working day, one person collects used HDPE milk bottles from the dry recyclables bins on each floor of a typical office building or segregated bins in coffee shops. If the bottles are damaged, usually in the corners and they are rejected and stay in the recycling bin, but the majority are in perfect condition. The dry tack labels are removed and the bottles washed ready for precision cutting. The solid walnut, oak and plywood used for the lids are sourced by Goldfinger Factory are made from a variety of waste timber sources including furniture worktops, flooring and factory offcuts. The lids are precisely machined using a combination of CNC cutting and hand finishing techniques.

In total, the project could reduce The Crown Estate's operational waste by 600 tons a year, implementing initiatives such as re-usable packaging, product reuse and upcycling. Aside from upcycling low value waste into functional products that are more valuable, the most satisfying result of the project so far is the creation of creative design, manufacturing and commercial skills required to turn upcycling into a viable business. Initiatives like this foster new and exciting opportunities necessary to kick start the upcycling industry.

Left and above:
Waste plastic bottle harvesting and cutting; **Golborne upcycled product range** for Goldfinger Factory.

SEATING AND FURNITURE

FROM WOODLAND TO WORKSHOP AND BACK AGAIN

Image: **The Vitra Design Museum's Schaudepot gallery** in Weil am Rhein forms an important part of their chair collection and demonstrates how chair design has mirrored cultural and design thinking through the 20th and 21st Centuries.
© Vitra Design Museum, Mark Niedermann

Above: Wooden chair components turned on a pole lathe

Seating and furniture is one of the most fascinating barometers of cultural and technological change since the first built in seating and furniture was developed around 3180 BC by Neolithic man as part of their stone and timber dwellings, examples of which survive at Skara Brae on the Orkney Islands. Early seating was largely treated as a symbol of status and ceremony and it's true to say that chairs and furniture continue to reflect our changing times.

As we entered the Industrial age, timber chair production inevitably moved from rural production to factory based production. Tools such as the pole lathe used to turn the legs and stretchers and the steam boxes and jigs used to bend the bow backs and arms for the popular Windsor chair of the 18th century initially located in the woodland where the timber was harvested moved to the workshop.

In Germany, Michael Thonet and his brothers moved from workshop to factory production for their lightweight and elegant No.14 Bentwood chair designed in 1859. The firm's key design principle was to manufacture as many chair models as possible from as few parts as possible.

These parts were then packed in boxes, for ease of shipping, and assembled elsewhere by the distributors or retailers. In this way, Thonet was able to increase production from 10,000 chairs per year in 1857 to 1,810,000 by 1913. Both chairs used steam bent timber and remain poplar today.

To reflect the modern 'machine' age and simplify chair production further, Thonet started the serial production of Marcel Breuer's first tubular steel Wassily chair in the early 1920s and Mies van der Rohe's cantilevered chair in the late 1920s.

Like Henry Ford, Thonet exhibited at many international fairs and established a global reputation. They built a worldwide network of retail outlets and, from 1859, published multi-lingual catalogues showing every model, individually numbered, to facilitate orders. Their strategy proved so successful that by 1930 over 50 million model No. 14 chairs alone had been sold.

Thonet's strategy to market and manufacture their products globally to supply a burgeoning population is mirrored by other manufacturing pioneers across other industries during the industrial revolution.

Right: **The Thonet Chair Factory** in the 19th Century; **Charles Eames** DAW Chair; **The Mirra office chair** by Herman Miller is one of many chairs that represent current state of the art office chair design and technology. The chair achieved a Bronze rating in the Cradle to Cradle product standard and a gold rating for material reutilisation.

Moving on 30 years or so, we saw the development of Charles and Ray Eames moulded plywood and GRP chairs for Herman Millar and Robin Day's pared down polypropylene chair for Hille. Herman Millar, Knoll and Vitra in particular have concentrated on technology driven seating to provide responsive seating for office workers. There is now a plethora of different furniture manufacturers offering different approaches and specialisms to furniture design and manufacture. For this study, with such a diverse market, we have looked at closed loop initiatives implemented by small, medium and large manufacturers in the past two years or so.

Re-use on Large, Medium and Small Scales.

Today, Ikea is the largest furniture manufacturer in the world, with 392 shed warehouse stores generating 38 billion Euros of revenue in 2016. The multinational company founded by Ingvar Kamprad in Sweden is responsible for approximately 1% of world commercial-product wood consumption, making it one of the largest users of timber in the retail sector. Much of their product range uses particle board, connected by the ingenious cam and pin fixing allowing the user to quickly dry fix the components together, also allowing component separation at end of life. The challenge for IKEA and other furniture manufacturers is how to offer products where materials can be separated at end of life. Particleboard panels impregnated with resin and laminated with resin based melamine and high pressure laminated surfaces, make recycling such composite materials a challenge.

IKEA's products, building stock, production and logistics are very efficient, reducing costs and allowing them to offer convenient and price competitive products. IKEA is addressing the need for products that reuse waste material as a resource, developing some upcycled products as part of their PS range, launched in 2017. The range is intentionally design led and a touch more expensive than IKEA's other products and this reflects the higher cost of using recycled material over virgin. The Odger chair is moulded from 70% recycled plastic impregnated with 30% wood fibre. Door panels used for their Kungsbacka kitchen cabinet use recycled plastic from waste PET blow-moulded bottles, again reinforced with timber fibre.

At face value, although IKEA's first steps to offer products that reuse waste material is admirable, there is a material and moral dilemma. Because woodchip is used to reinforce and fill the recycled plastic, the new composite materials will be virtually impossible to re-separate and re-use at end of life, so incineration or landfilling may be the only solution. On a more positive note, the waste materials used for these products are serving a secondary purpose, but can these materials be used in a way that prevent contamination? Perhaps Ikea can offer a chair repair service to fill, sand and extend the life of these products indefinitely as the designs have a long term appeal.

A naturally smaller, but perhaps more radical approach to furniture made from upcycled material has been initiated by Rod Fountain and Mary Dorrington Ward, founders of Flute Office. Working with materials scientists, structural engineers and furniture designers, an intense period of research and development between 2010 and 2012 culminated in the launch of their first flat-pack desk manufactured from waste cardboard in 2011.

Further experimenting with cellulose manufacturing processes, product development and sales led to additional public funding and private investment, allowing Flute to set-up its manufacturing and upcycling centre of excellence in 2016.

The range is intentionally design led and more expensive than IKEA's other products and this reflect the higher cost of using recycled material over virgin.

Image:
The Odger Chair.
© Ikea

© Flute Office

Flute now converts several thousand tons of low value waste cardboard and paper into higher value furniture on a large scale. The process mixes shredded paper, cardboard, textile and coffee cup fiber with water and organic additives. The pulp is screened, pressed and dried to form upcycled sheet material that is not contaminated with resins and glues and has performance characteristics similar to MDF. Flute is set up to use thousands of tonnes of waste material to manufacture thousands of items of furniture, wall systems and signage.

To encourage closed loop product lifecycle, Flute clients can subscribe to Flute's furniture supply service, buy or lease the furniture. Flute will take back the products and replace them with new upcycled products. The old products are re-processed and converted back into new furniture, partitions and signage.

Office furniture such as workstation desks and storage units often have a relatively short lifespan of just 7-20 years as they tend to mirror changes in technology and work trends, so it makes sense for manufacturers of this furniture to better plan for closed loop production.

A fascinating, small scale and inventive example of problem solving through upcycling was initiated by London based furniture designer Carl Clerkin and design led furniture manufacturer SCP. Much of Clerkin's work is playful, but 'to the point', integrating found and ready-made objects as components.

SCP was set up by Sheridan Coakley in 1985 and over the years they had accumulated a number of damaged, broken and unusable furniture pieces in their warehouse. Instead of disposing of these broken and damaged pieces, Clerkin worked with like-minded designers Danny Clarke, Neil Austin and Jasleen Kaur and set about creating new, one-off furniture pieces that were cleverly cut and reassembled to create new one-off furniture pieces from the remains.

To raise awareness of this initiative, the new designs were exhibited at the SO gallery in East London and finally sold at an auction evening at SCP, with proceeds going to the designers and Cancer Research charity Maggie's. What's interesting about this initiative is how many of the chairs and tables are made up of seats, backs and leg bases from well-known classics by Charles Eames, Robin Day and Marcel Breuer. Clerkin's pieces are as much a reflection of our times where refurbishment makes more sense than disposal. The initiatives by Ikea and Flute demonstrate how seating and furniture continues to reflect our growing concerns about waste and climate change. Our challenge is for these and other initiatives to be adopted on a much larger scale and for us, as consumers to demand these new initiatives and re-production processes as standard practice.

Left and above: **Workstations and Storage** by Flute Office; **Furniture upcycling,** Carl Clerkin

METALLURGY

NEIL PERRY

© Erdenebayar Bayansan

AND THE DEVELOPMENT OF LOW CARBON VEHICLES

Human evolution and history is defined by metals. The 'Bronze Age' and 'Iron Age' are so called because of tools crafted from iron and copper alloys by early humans. Iron constitutes some 5% of the earth's crust, existing in the form of different ores. Iron ore is easily extracted and converted into elemental metal. Aluminium is more abundant than iron and constitutes 8% of the earth's crust. Unlike iron ore, aluminium is difficult to convert into elemental metal and requires a series of complex processes. This explains why our ancestors didn't discover aluminium as readily as copper and iron.

The production and characteristics of the steels used in industry today were developed and understood in the late 19th century. The discovery was underpinned by the study of swords and knives, perfected by heating, folding, and hammering red hot iron. It was revealed that hot working reduced impurities and the carbon content of early cast iron.

The discovery led to a preliminary understanding of the behaviour, properties and performance of modern steels, a key milestone in industrial development.

The Bessemer steelmaking process was developed, using techniques to produce quality steel by modifying batches of steel in the molten form to achieve strength characteristics, blowing air through molten pig iron to remove the impurities. This made steel easier and quicker to manufacture reducing costs, a revolution for structural and mechanical engineering. Steel remains one of the most predominant materials in the built environment and the manufacture of vehicles. The material was essential for the development of screws, nuts, bolts and clips, those small but critical components that allow secure, dry assembly and robust connection of parts that also allow products, vehicles and components to be repaired, replaced or cleanly disassembled at the end their useful of lives.

Metal Recycling

Iron, steel and aluminium are relatively easy to recycle by re-melting. Recycling reduces reliance on mining, conversion and smelting of metal ores. Mining, conversion and smelting processes are costly, high in energy consumption and result in significant environmental implications from land use, waste (tailings) and emissions. The recycling or re-melting of scrap iron and steel requires approximately 30% of the total energy compared to smelted ore. The re-melting of scrap aluminium requires approximately 5% of the total energy compared to smelted ore. The value and possibilities in re-melting iron, steel and aluminium depend strongly on the extent of separating, cleaning and processing of scrap material. There is significant interest and development in the reuse of metals – this is an area of even greater benefit from a cost and environmental perspective. Recycling requires management and separation. This is a key part of the recycling process and reduces contamination or undesirable effects.

Open-Loop or general scrap metal comes with a plethora of contaminants including paints, coatings, foodstuffs, oils, lubricants, plastics and glass, a large proportion of which has to be removed before re-melting.

The first stage separation of steels and iron is very simple because of their magnetic properties. Magnets can extract these materials from a conveyor belt of mixed waste. Aluminium

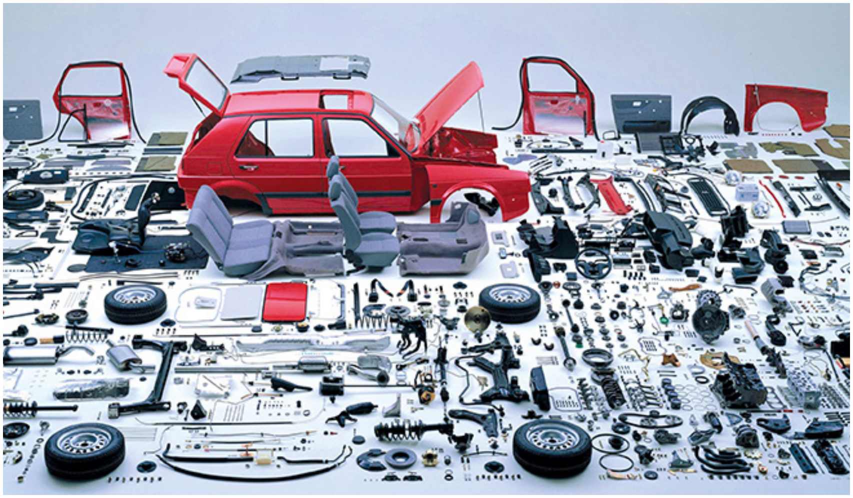
requires the use of more complex ‘eddy current’ separators to deflect this material from a mixed waste stream. The quality and acceptance of scrap metal for re-melting is influenced by the form and extent to which processing, separation and characterisation occurs. Scrap metal is generally sorted into bulk solids or large sections which can be placed in a furnace in solid form, or small fines such as swarf and bailed materials, including cans and containers that are pressed into blocks or bales. Generally, bulk solids and large objects are more valuable because of reduced processing, however the technology of separation and sorting is developing rapidly.

Closed-loop scrap metal is a valuable source of material in addition to open-loop or post-consumer metal. Many foundries and metal processors revert and return waste by-products generated during processing. Most waste management organisations define contracts and specifications for well defined, segregated and characterised scrap from manufacturers. These contracts require controls and segregation of waste streams and types, resulting in more valuable scrap that requires less sorting and processing and is inherently well characterised. A common scrap classification system is the ‘ISRI scrap specifications circular’. Many foundries define categories for the type and form of scrap for different processes and products that they will purchase from recyclers.

Image:
Pressed metal blocks from car waste allows for efficient transportation and re-smelting

THE RECYCLING OF SCRAP IRON AND STEEL REQUIRES APPROXIMATELY 30% OF THE TOTAL ENERGY COMPARED TO SMELTED ORE.

The melting and alloying process is similar in principle to baking a cake. In order to meet international standards and product requirements, the ingredients of the 'cake' must be carefully defined and controlled. Most foundries require recycled materials in graded form to achieve this. Understanding the constituents of recycled scrap is key to achieving an acceptable product – in many cases, scrap is melted with 'virgin' alloys, produced from ores to achieve the required standard. The level of control and quality of sorting influences the extent to which scrap can be recycled.



Car Assembly, Disassembly and Recycling

The car recycling industry is relatively well developed. Just after the turn of the 20th Century Henry Ford set up the Ford Motor Company and first Model T car assembly line in Michigan. Since then, the component parts developed for high volume car production have made the repair, refurbishment and recycling of cars relatively efficient. Car parts are designed to be mechanically fitted together at speed and this makes car recycling straightforward and cost effective. Spare parts, even for cars that have fallen out of production are relatively easy to source as the parts can be harvested at the end of the vehicles useful life and spare parts continue to be manufactured all-be-it in smaller batches.

In 2000, The European End of Life Vehicle Directive (ELV)[8] harmonised European legislation for vehicle recycling. Aimed at cars and light commercial vehicles, the directive encompasses the design, requirements for collection and treatment facilities, the attainment of targets for reuse, recycling and recovery of vehicles components and materials at end of life. Since the introduction of the ELV, European car reuse and recycling rates have increased from 6.3 million in 2008 to around 10 million in 2017.

Car recycling starts with vehicles being inventoried for parts. The wheels, tyres, battery and catalytic converter are disconnected and removed. Fluids such as fuel, oil, coolant, transmission fluid and air conditioning refrigerant are drained. Sodium azide, the propellent powder used to rapidly inflate air bags is also removed.

Images: **Disassembled** Volkswagon Golf; **Car assembly line,** Győr, Hungary.

Cars are generally assembled using pre-manufactured components and sub-assemblies that allows efficient disassembly, part replacement and reassembly, extending the life of the car. This approach, when combined with clear car recycling rules has resulted in more parts and materials re-harvesting at end of life.

© Audi AG.

© Jaguar Land Rover

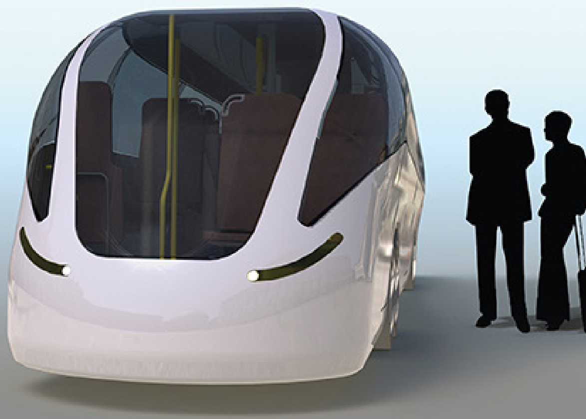
Parts such as electronic modules, alternators, starter motors, entertainment and information modules - even complete engines or transmissions are often removed if they are in working condition and can be profitably sold on; either in their used condition or to a restorer for repair and restoration. Interior seating, trim panels and linings are often removed as are air conditioner evaporators, heater cores and wiring harnesses.

The remaining car body shell and chassis are crushed flat or cubed, to allow efficient batch transportation to an industrial shredder or hammer mill. Here, the vehicles are further reduced into much smaller nuggets of metal and residual materials known as automotive shredder residue (ASR). The remaining metals are sold in large batches to steel mills for recycling whilst the residual glass, plastic and rubber particles are removed for recycling or incineration.

Since the Model T Ford, cars are generally assembled using pre-manufactured components and sub-assemblies that allows efficient disassembly, part replacement and reassembly, thus extending the life of the car. This approach, when combined with clear car recycling rules has resulted in higher parts and materials re-harvesting at end of life.

A move to lightweight vehicles

The fluctuating and volatile nature of crude oil prices and debate as to when peak oil extraction will be reached highlights the need for lighter, more fuel efficient and responsive vehicles to transport people and goods. Although steel remains the most popular material for vehicle manufactures, lighter aluminium is becoming the material of choice for certain car manufacturers such as Audi, Tesla, BMW and Jaguar developing a growing number of aluminium and even the first titanium component in their cars. Compared to steel, it is softer, more expensive and harder to manipulate, so not used on the majority of vehicles. However engineering, metallurgical and manufacturing ingenuity is resulting in more aluminium car components. Jaguar have carried out an 8-year research 'REALCAR' project with aluminium recycler Novelis and other



The autonomous vehicle is intended to allow people to travel rapidly into, under and across small cites in a matter of minutes.

stakeholders to develop a closed-loop production vehicle.

Its new aluminium alloy, containing up to 75% recycled content has been successfully used for structural components in their production cars. The company was able to reduce the amount of waste it sends to landfill by 79% by vehicle, ahead of a target to achieve zero waste to landfill by 2020.

21st Century Vehicle Technologies – 'A period of transition'.

New modes of public transport that combine lightweight materials with electric power-trains such as the AVRT (Advanced Very Rapid Transport) vehicle could offer low carbon modes of transport that use existing power and material technologies. The autonomous vehicle is intended to allow people to travel rapidly into, under and across small cites in a matter of minutes. The high speed electronic vehicles will look more like a bus than a train or a tram and they do not need a track or tram lines to run or, indeed, a driver. The vehicles could run in convoy along a dedicated guide-way, both above and under the ground, allowing dozens of passengers to board at any one time. Professor John Miles, holder of the University of Cambridge energy research post which is co-sponsored by Arup and the Royal Academy of Engineering reflects the growing interest in how society can build toward a lower carbon future while supporting sustainable economic growth.

"The AVRT is an electric vehicle which is being developed deliberately to make public transport more attractive than using a car – to all people, including the most affluent. It therefore needs to be very speedy and run very frequently. The AVRT would run at speeds of 120mph – the system we are looking into does also run slower than this, but this would actually make it more expensive, as you would need more vehicles to keep the service as frequent".[9]

Above left and right:
Jaguar aluminium body structure;
Advance Very Rapid Transport (AVRT) vehicle concept


Hier
Strom
tanken!

These are fascinating times for vehicle design, technology and legislation. The industry is entering a disruptive period with nations and regions from China to California considering a widespread ban on the internal combustion engine over the next 10 to 20 years. Most car manufacturers are planning to launch all electric vehicles, despite questions over how clean the source electricity will be, the practicalities of charging times and the continued supply of lithium batteries required to power them. Additionally, manufacturers have started preliminary production and testing of autonomous vehicles with 5 levels of autonomy from driver assistance (level 1) to full automation (level 5) where the driver makes no decisions.

Theoretically, level 5 autonomous vehicles may become the panacea to urban traffic congestion and the sheer number of vehicles on the roads. Vehicles could be 'on demand' and shared. Vehicles that have been used by one person for a journey to a mass transit railway station could be used by another group of users for another journey so that less cars stand idle or parked when not in use. The travelling time could be used for a range of other in car activities such as relaxing, working and networking.

For medium to long distance travel, trains will continue to play an essential role for fast mass transportation. The considerable investment required for rail infrastructure and trains ensure they have a relatively long lifespan. For instance, one of the first high speed trains, Kenneth Grange's iconic Inter City 125 was developed and introduced to connect the UKs major cities in 1975. The original power trains and rolling stock, refurbished from time to time are still transporting thousands of people in 2017, over 40 years later. Like cars, because of their extended lifespan, they need to be designed using mechanical, robust but easy to replace parts and sub-assemblies to allow rolling stock refurbishment and encourage efficient disassembly at end of life. Trains are a valuable source of metal and other materials for future products.

Most car manufacturers are planning to launch all electric vehicles, despite questions over how clean the source of electricity will be...

Image: Electric vehicles recharging.

A long-distance mass transit development project is Hyperloop One. Originally proposed by Elon Musk one of the instigators of Tesla, the Hyperloop is based on the idea of magnetically levitating pods that would travel in near-vacuum tubes at over 700mph, powered by an electro-magnetic propulsion system that allow the pods to glide at high speed for long distances [10].

He proposed the idea as an alternative to California's high-speed rail project; a Hyperloop journey from Los Angeles to San Francisco could take only 36 minutes by Musk's calculations and cost under $6 billion (£4.88 billion), compared to the $68 billion (£53 billion) estimated costs for the rail project.

The first propulsion system tests and tube test structures are currently taking place in the Nevada desert. John Miles and ARUP have partnered with Hyperloop One in the UK. *"There's an engineering challenge in getting the system to work, but I don't see why we couldn't overcome it."*[11] Careful trials and analysis will determine which materials are used for these new modes of rapid transportation and the tube sections and connections required for the Hyperloop infrastructure.

Vehicle manufacturers have successfully used a mixture of mechanical, composite and adhesive joining technologies to construct and connect lightweight vehicle components. However, to ensure easy material separation of materials at end of life, it's the humble nut, bolt, screw and clip that are the key components that will allow for robust assembly during production and rapid disassembly ready for reuse at the end of a vehicles useful life.

Having considered the challenges facing large scale builders and manufacturers seeking to reduce material costs and increase efficiency through closed loop design and energy efficient lightweight materials we are going to consider how society can deal more effectively with the waste it creates.

Right:
Arup's Hyperloop vehicle and station design.

NEW YORK'S WASTE INFRASTRUCTURE

JOSH TREUHAFT

Walk down almost any street on garbage day in NYC and you will inevitably be confronted by what I like to call the "Garbage Walls".

Sometimes they stretch almost the entire length of a city block nearly 6 feet high, a visual reminder of the volume of resources currently required to enable daily life for the 8.5 million people who call New York City home.

ABOUT JOSH TREUHAFT

Circular Initiatives in New York

Josh Treuhaft is a Design Strategist in Arup's Foresight, Research + Innovation Practice in New York where he examines how closed-loop systems thinking and circular economy principles can fuel the design of solutions to urban challenges in ways that keep resources at their highest and best use for the most people for the longest time. He is also the Founder and Creative Director of Salvage Supper-club, a multi-course dining event that transforms people's relationships to food (and helps reduce food waste) by leveraging the creative, social and sensorial dimensions of interactive communal meals. He has been actively shaping a more sustainable and resource efficient New York for the last ten years and has recently joined the board of BIG Reuse – the city's pre-eminent salvage, reclamation, and reuse organization for building materials and home appliances. He holds an MFA in Design for Social Innovation from the School of Visual Arts in New York.

Approximately 2.3 billion dollars is spent each year on garbage collection, sorting, movement and disposal.

© Dreamstime

At a macro level, the city currently produces 12,000 tons of waste every day with City government spending between $320m and $400m a year on waste export costs alone, shipping much of the waste to far-flung landfills in the Midwest and Southern US. As the city continues to grow and the needs of that expanding population put pressure on our limited space and resources, it stands to reason that the current model is not sustainable. We need to radically rethink our approach to resource utilization, re-utilization and management to grow and thrive in the 21st century and beyond.

In an effort to align the city's operations with its aspirations as a global leader in sustainability and innovation, they are taking immediate steps and making more robust action plans to reduce impact and improve quality of life. "Zero By 30 (0x30)" is the umbrella name the city has given to this initiative. In their most recent 2017 Reuse Sector Report,[12] they have established an ambitious goal of sending zero waste to landfills by the year 2030. The zero-waste approach encourages alternative solutions for the management of solid waste that can prevent valuable resources from being disposed of in landfills. By encouraging product-design improvements to facilitate repair and extend a product's useful life, and by expanding reuse and recycling opportunities, the zero-waste approach contributes to the circular economy, in which *"products are optimized for a cycle of disassembly and reuse."*[12]

When it comes to managing materials in the residential waste stream (e.g., recycling soda cans, composting food scraps, or anaerobically digesting food waste to create energy for the city), the Department of Sanitation (DSNY) can have a direct impact on processing and landfill diversion. But for reuse, upcycling and diversion of commercial materials to higher and better uses and beyond, they need to encourage innovative, 'circular' practices from a diverse set of stakeholders that sit across the NYC ecosystem.

BRIGHT SPOTS
AND INSPIRATIONS IN NYC

Like many other cities around the world, New York is on a journey. That journey is not without its current and future challenges, but despite these hurdles there is a growing legion of public, private and not-for-profit change-makers who are actively charting a course toward a zero-waste city. It's not within the scope of this short reflection to name all of them, but I'd like to share a few that I find particularly inspiring.

Bright Spots:
BIG REuse

BIG Reuse is a long-standing New York non-profit organisation that takes a multi-faceted approach to materials recovery and reuse. They run two warehouses selling a wide assortment of reclaimed materials, appliances, accessories and furnishings to the public at reasonable prices. They stock those warehouses from a range of sources: Their deconstruction crew removes items from homes and apartments in and around NYC; the public can donate materials; businesses can donate materials such as furniture from showrooms and commercial office renovations; film crews, Broadway shows and general contractors can all donate items. They run a salvage lumber mill, processing reclaimed lumber for use on construction projects around the city and they are instrumental in the city's roll-out of composting, educating the public, and collecting and processing more than a million pounds of food waste a year into rich organic fertilizer.

https://www.bigreuse.org/

Bright Spots:
Ecovative

Ecovative is not technically based in New York City as the HQ is in Green Island New York, but they are truly a world-changing organization and a shining example of a transformative, closed-loop, product portfolio with a financially sustainable business model. Their mission is to "*envision, develop, produce, and market Earth friendly materials, which, unlike conventional synthetics, can have a positive impact on our planet's ecosystem.*" The primary product line uses local agricultural waste materials coupled with patented biological technologies (primarily mushroom-based) to produce materials that outperform conventional alternatives but are made entirely out of harmless natural materials that would decompose naturally under the right circumstances. From Styrofoam packaging substitutes, to Mycoboard (MDF substitute) and beyond, their products are making it possible to hit cost, performance, health and environmental targets across an array of sectors.

https://www.ecovativedesign.com/

© Ecovative

Bright Spots:
Brooklyn Bridge Park

Brooklyn Bridge Park is one of my favourite places to spend a Sunday afternoon. It's the result of a successful redevelopment of a waterfront industrial district that's been painstakingly transformed into a public amenity filled with beautiful skyline and river views, pocket parks and inviting landscapes with a wide range of amenities including picnic areas, athletics fields, restaurants and fishing areas. Beyond all that, it is filled with upcycled features so all of the tables and benches in the Picnic Peninsula and on Pier 1 are made out of reclaimed long leaf yellow pine from the cold storage warehouse that used to sit on the site.

The Granite Prospect sitting and viewing area is made entirely of materials salvaged from the Roosevelt Island bridge project, and the shed coverings for the sports complexes on Pier 2 are repurposed from old Port Authority sheds. By upcycling locally-sourced materials from decommissioned projects, the park was able to reduce material mileage and embodied carbon, contribute more to the local economy, save on materials costs and create a rich and meaningful story that connects the park directly to the history of the city and the site.

Left to right: Brooklyn Bridge Park seating; **Reclaimed materials** used for stepped seating area

© Brooke cagle

Bright Spots:
NYC Centre for Materials Reuse (NYC CMR)

The NYC Centre for Materials Reuse was established by the Department of Sanitation in partnership with the City College of New York's Grove School of Engineering as a first-of-its-kind R+D program focused on tracking and empowering more reuse in the city. Its primary activities include:

1) Ongoing research on local and global models for materials reuse that could be applied more widely in NYC,

2) The collection and processing of verifiable data about greenhouse gas emissions, energy consumption and materials diversion in the city,

3) Supporting the growth and development of local NGO's that redistribute goods and materials to support social services and workforce development.

They are also responsible for the development and operation of the NYC Reuse Impact Calculator, a data processing system to track reuse metrics in NYC.

http://www.nyccmr.org/

Bright Spots:
Pop-up Repair

Pop Up Repair is an "itinerant repair service for household items." They open short-term "shops" in neighbourhoods across NYC such as empty storefronts, at greenmarkets, and inside other businesses, to meet their customers in the most convenient local places. Anyone with items in need of repair can drop it off, pay a small and fair fee, and pick it fully repaired before the Pop Up moves on to its next location. Over the last 3 years, they've taken in more than 2,000 broken items and have a success rate of more than 85% of them. Repairing items helps avoid sending additional waste to landfill, but also reduces the demand (and material implications) of new items made from virgin feedstocks. It reduces material mileage and creates local income streams, and most importantly, over time helps to shift the cultural mindset about disposability and material value.

http://popuprepair.com/faq/


© Pop up Repair.

Bright Spots:
Recycled Brooklyn

Recycled Brooklyn is a family-owned and operated, furniture design and home goods company, founded by brothers Matthew and Steve Loftice. They design and build furniture for individuals, restaurants, offices and hotels using a wide range of salvaged and reclaimed materials culled from sites across NYC. Their 2-column "Brooklyn Dresser", for examples, is made of material that was cut from floor beams salvaged across greater NYC. While their operation is relatively small with 10 fabricators in an 8,000 square foot workshop, their pieces show the type of quality that can be achieved using high quality salvaged materials with older vintages to create contemporary furnishings and experiences.

https://recycledbrooklyn.com/

Steve Loftice of Recycled Brooklyn re-machining salvaged timber. © New York Times.

CONCLUSIONS - ZERO BY 30 AND BEYOND

For much of our history, we have lived in a Linear City, where materials primarily flow from cradle to grave. We dig up raw materials from the earth, turn them into products, and ship those products to people who use them and discard them into a landfill. The paradigms are slowly shifting on a global scale to a more circular model. It's a model where materials and products are used and then reused, reconstituted, refurbished, renovated and re-imagined in perpetuity. Sending zero waste to landfill and processing as much as we can locally. New York can and will become a Circular City. It is already filled with industrious, proactive, transformative organizations that are working tirelessly to enable that shift. They are all doing things in their own unique ways, working at different scales with different strategies, and filling different roles in the wider system. We are taking a multi-pronged approach at a range of scales, and that gives us a more diverse and resilient system. Some are big and some are small but all are valuable even if just for helping the world see that we can do things differently. Ideally, we will see many more organizations and new approaches emerging and evolving in the years to come and before we know it, the idea of getting to "Zero by 30" will be a thing of the past. People will look back wonder how it could be that there was a point in time when so many valuable materials were being so systematically underused.

The NYC story is one that should hearten us all however not all solutions can be found at the user end of the journey. The city is finding solutions to a problem through innovation and lateral thinking. Going forward cities and governments need to have a more planned and cohesive approach to the reuse of waste. Switzerland has taken the lead here using a form of surcharge to enable consumers and manufacturers to "close the loop" for technological waste.

NEW TECH

AND THE CHALLENGES OF E-WASTE

Developments in communication and technology products during the past 35 years have been nothing short of meteoric. This coupled with the launch of the world-wide web in 1991 have fundamentally changed how we communicate, share data and work.

Since Motorola developed the first mobile phone prototypes in 1973, launching the Dyna TAC 8000x production model ten years later, phones have become some 20 times smaller and 8 times lighter. Aside from this reductionist improvement, the integration of high resolution interactive screens, development of smart applications and improving connectivity infrastructure have transformed the functionality of these devices for users. Personal computers have followed suit, becoming ever more mobile and intuitive. The size and weight reduction of these products, have helped with device usability and an overall reduction of physical material required to manufacture them and manage at the end of their functional lifespan.

Thanks to an increase in processing power and battery life, faster network speeds and larger touch screens, people prefer to use their smartphone, coupled with a laptop or tablet as their main communication and connectivity device. Research shows that approximately 43% of the global population use a mobile device[13], while data from the Association of Global System for Mobile Communications reported the number of active mobile devices overtook the global population in 2014.[14 / 15]

Image: E-Waste Recovery Centre.

© Recycle for Lewisham.com

© Stephen Philips, Arup


© Stephen Philips, Arup

E-Waste Regulations & Logistics

An awareness of the need to recycle electronic waste (e-waste) started in the early nineteen nineties. In 1991, the first electronic waste recycling scheme was implemented in Switzerland by the Swiss Economic Association for the Suppliers of Information, Communication and Organizational Technology (Swico). Starting with collection of used refrigerators at designated collection points, retailers and suppliers, the system gradually introduced the collection and recycling of all other electronic products.

Manufacturers and importers of new electronic goods pay the Advance Recycling Fee (ARF) on equipment sold in Switzerland and Liechtenstein. These costs are passed on to end users by product distributors and dealers.

In return for paying the ARF, the end user is entitled to hand in their used equipment free of charge to manufacturers and importers or at a collection point. The collection points forward the equipment to one of the designated Swico specialist electronic waste recycling companies. At these recycling companies, the products are dismantled, components containing pollutants are removed and the other parts are taken apart so that recoverable materials can be salvaged. The logistics, recycling and management process is financed by the Advance Recycling Fee.

Regulations specify that manufacturers and importers that do not pay contributions to a private organisation such as Swico Recycling are to dispose of the equipment taken back at their own cost. In addition, they are required to maintain an inventory of equipment that they sell and take back, and must be able to provide evidence that they have forwarded it for recycling. The Swiss Federal Office for the environment have the right to inspect these documents for the previous five years. All in all, the cost of going it alone is considerably higher than becoming a member of Swico Recycling as required by statutory regulations is adhered to otherwise, companies run the risk of damaging their reputation and being heavily fined. The scheme is the most successful of its kind as the total amount of recycled electronic waste exceeds 10kg per capita per year [16].

The European Union implemented the Waste Electrical and Electronic Equipment (WEEE) Directive in February 2003. The Directive provides guidance on take back schemes, collections, recycling facilities and responsibility of the different stakeholders at each stage of the product life cycle. The directive imposes the responsibility for the disposal of waste electrical and electronic equipment on the product manufacturers or distributors and requires those companies to establish an infrastructure for collecting electronic waste, in such a way that: *"Users of electrical and electronic equipment from private households should have the possibility of returning WEEE at least free of charge"*[17].

The directive saw the formation of national producer compliance schemes into which manufacturers and distributors pay an annual fee for the collection and recycling of associated waste electronics from household waste recycling centres. The application of the WEEE Directive has been criticized for implementing the Extended Producer Responsibility (EPR) concept in a collective manner, and thereby losing the competitive incentive of individual manufacturers to be rewarded for designs that allow easy disassembly and material separation at end of life.

Images left:
Waste Electrical and Electronic Equipment Bank; **Airstream** Organic Light Emitting Diode (OLED) smartphone and pad product concepts.

It is perhaps inevitable that solutions to the challenge of reducing waste create new problems and issues.

EPR is an environmental protection strategy intended to reduce the total environmental impact of a product, passing responsibility for the entire life-cycle of the product and especially for the take-back, recycling and final disposal to the manufacturer or importer. Under the directive, each European member state recycles at least 4 kg of electronic waste per capita per year.

In 1993, journalist Steve Lohr's article highlighting the need to recycle electronic waste was published in the New York Times.[18] The US Environmental Protection Agency (EPA) estimated that 11.7 million tons of e-waste was generated in 2014.

The United States does not have an official federal e-waste regulation system, yet certain states have implemented state regulatory systems. The National Strategy for Electronic Stewardship was co-founded by The Council on Environmental Quality and the General Services Administration (GSA) and was introduced in 2011 to focus on federal action to establish electronic stewardship in the United States. In many states, approximately 2.5kg per capita per year of electronic waste is recycled. Like the majority of nations, the United States e-waste management includes waste to landfill and e-recycling and reuse programs as well as export shipments of domestically produced e-waste to China, Africa, Latin America and India.

It is perhaps inevitable that solutions to the challenge of reducing waste create new problems and issues.

Printed Circuit Boards and Batteries

The scrap value for the plethora of e-waste components and materials varies tremendously. They contain recoverable, reusable materials such as steel, aluminium and thermoplastic product housings and etched copper sheet, contacts and core cable however the other precious metals which make up the cocktail of materials in advanced Printed Circuit Board (PCB) can only partly be recycled. The epoxy glass laminate substrate has no value and cannot be recycled back to its constituents, but the gold, silver, tin and copper plated contact surfaces provide the most valuable e-waste materials that can be recovered from the PCB through a range of often hazardous melting and chemical processes.

In 2012, a revised WEEE Directive[19] introduced restrictions to the use of certain hazardous substances and materials. However, as most current e-waste is pre-2012, e-waste materials often include lead, mercury, cadmium, hexavalent chromium, sulphur, brominated flame- retardants, perfluorooctanoic acid and beryllium oxide, all of which are extremely hazardous to human health without carefully implemented precautionary measures.

The unprotected and labour-intensive nature of e-waste material harvesting often causes serious environmental,

health and social issues.[20] Guiyu is a town in the Guangdong Province in southeast China and is one of the largest e-waste sites in the world, one of several examples of a community living off the recycling economy of digital products' waste. The air, water and soil are contaminated with these harmful materials. Much of Guiyu's 150,000 population work in the 5,500 material recovery businesses, many of them family workshops, that dismantle old electronics to extract lead, gold, copper and other valuable metals. The workers usually carry out extraction tasks without any protection and are therefore exposed to highly toxic and carcinogenic emissions. People working in this sector have 54% higher levels of lead in their blood, compared to people living and working 30 kilometres away. The low purchase price for scrap PCBs at just 0.13 dollars per kg[3], yet it provides a $3 billion market for recycled materials harvested by cheap, often child labour in poor working conditions, with devastating health and environmental consequences makes it an industry and market sector badly in need of resolution.

Above:
Worker cable harvesting. Guiyu in Guangdong Province is the location of the largest electronic waste site on earth; **Printed circuit** board fabrication

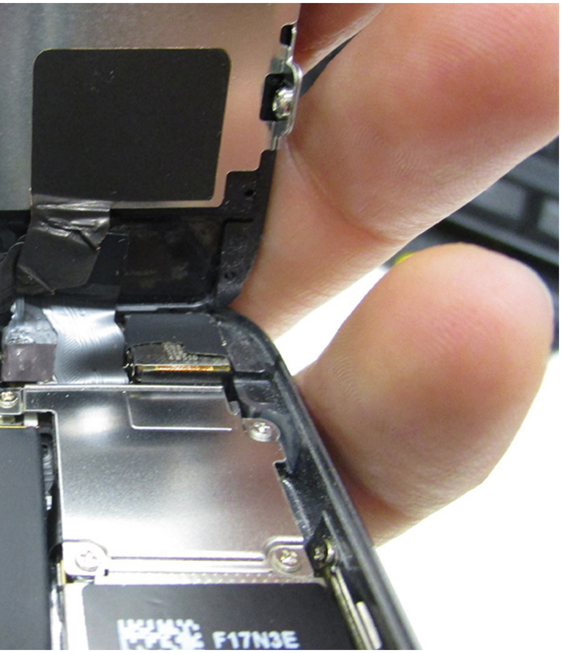
The treatment of WEEE in industrialised nations varies significantly depending on the category and technology type. Treatments range from large-scale shredding technologies to disassembly processes, either manual, automated or combined, according to the facilities.

So solutions to deal with e-waste are being developed but the high human cost of some of these systems needs to be addressed.

Batteries also represent a challenge to recycle. Although dedicated disposal containers are available in many shops and supermarkets, only 20 to 40 percent of Lithium Ion batteries in mobile phones and other consumer products are currently being recycled. Once collected, they need to be sorted by chemical constituents before going through an energy intensive process to separate and retrieve the metals from it. Indeed, reclaiming metal from some recycled batteries can take 6 to 10 times more energy compared to mining.[21] A Pyrometallurgical process is generally used to retrieve valuable materials from NiCd batteries. The recovered Cadmium and Nickel enriched iron can be used as raw materials in stainless steel production.

The greatest environmental concerns relate to lead and cadmium-based batteries. In 2009, this resulted in a European directive to ban the sale of Nickel-cadmium batteries containing more than 0.0005% of mercury and 0.002% of cadmium, except in emergency and alarm systems, medical equipment and cordless power tools. The directive calls for collection points to be established where consumers can hand in used batteries at no extra cost. All batteries must be removable, and all producers of batteries must be registered and bear the cost of battery recycling. Since the directive, the high energy density, slim profile and slow discharge rates of Lithium Ion batteries have made them the a most popular and effective replacement to Nickel Cadmium, despite their higher production and material costs.

Professor Philip Nelson, chief executive of the Engineering and Physical Sciences Research Council, said: "Batteries will form a cornerstone of a low carbon economy, whether in cars, aircraft, consumer electronics, district or grid storage. To deliver the UK's low-carbon economy we must consolidate and grow our capabilities in novel battery technology."[22] The UK government recently announced £246 million, to be spent over four years on research and innovation in battery technology. It is likely to have particular benefits in the automotive and renewable energy sectors.



...solutions to deal with e-waste are being developed but the high human cost of some of these systems needs to be addressed.

At present there are around 33 lithium ion battery mega-factories globally. China is the largest producer by far providing 62% of the world's production, enough to store 108GWh of electricity. Production in South Korea and the USA is increasing and this will include Tesla's new solar powered Gigafactory in the Nevada desert, intended to provide 35GWh of Li-ion batteries to meet its planned production of 500,000 Tesla cars per year by 2018.[23] We need to ensure that closed loop design principles are used in the development of new battery technology so that batteries have a long and sustainable user life and materials can be harvested safely and economically at the end of their user life.

Smartphone Tear-Down and Industry Initiatives.

To understand what it takes to recycle a digital product, we disassembled a state of the art smart phone with a view to harvesting materials for recycling. We found that due to over moulding (a process where a single part is created using two or more different materials in combination), it was virtually impossible to separate the aluminium housing from the over-moulded plastic features and components. When designing those connections, a push fit or screw fix approach could be more appropriate to allow the repair, separation and reuse of materials at the end of the product life.

Initiated as a reaction to the complexity and environmental impact of the smart phone manufacturing ecosystem, Fairphone was founded by Bas van Abel in Amsterdam as a social enterprise company in January 2013, having existed as an awareness raising campaign for two and a half years. The company have developed their closed loop smartphone with a repair and take back service, "designed and produced with minimal harm to people and planet"[24]. The project started in 2010 as a campaign against the use of minerals extracted in conflict regions, but the team thought it was better to actually develop a "fair," or ethically built, phone than start another petition campaign.

Images Left:
Smartphone tear down; **Lithium** Batteries

"As technology advances rapidly, consumers have lost any ability to modify, repair, and truly understand how they can keep their devices longer".

Fairphone's objectives are to source materials that are less hazardous and toxic, increase use of recycled and/or renewable material and to source materials from mines that empower vulnerable communities or have better sustainable performance. They also acknowledge that smartphones are often upgraded or discarded every 18 months, creating a considerable environmental impact. *"As technology advances rapidly, consumers have lost any ability to modify, repair, and truly understand how they can keep their devices longer"*.[25] To counter this, Fairphone have designed a modular phone, built to allow users to repair and replace components and extend the product lifespan. The company provides official tutorials for users to fix their phone themselves and spare parts can be purchased online. This modular approach not only extends the life of the phone but also eases dismantling at end of life to increase material harvesting opportunities.

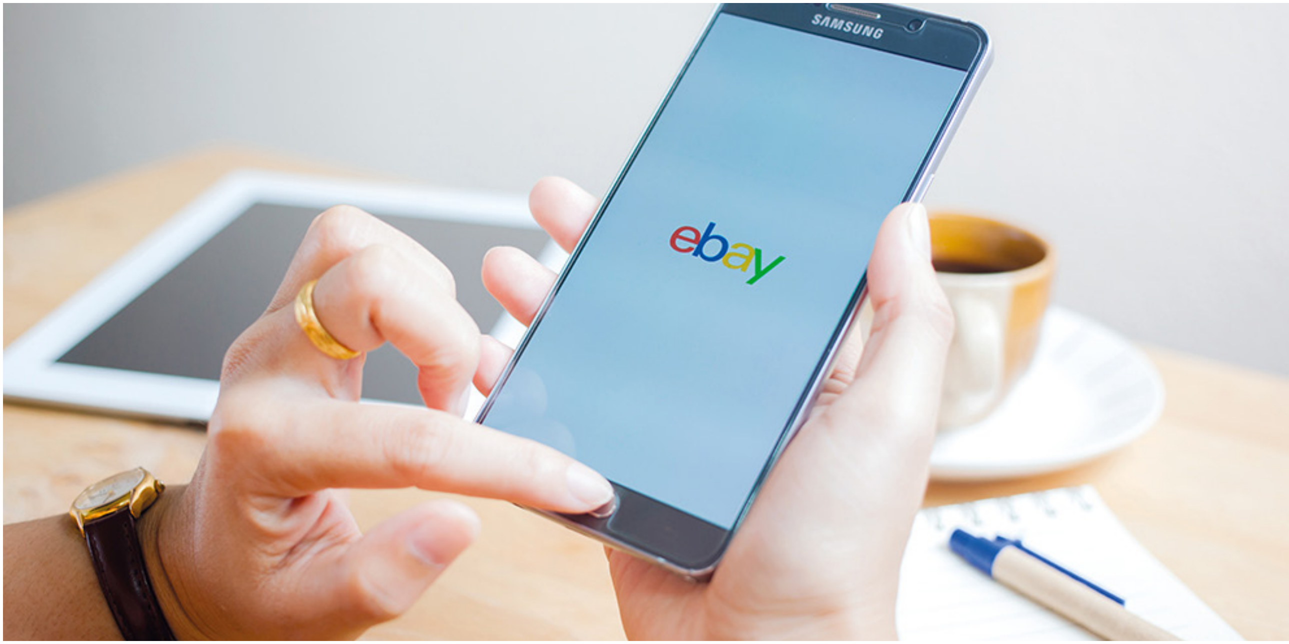
A study into 3 potential methods of Fairphone materials recovery found that partial dismantling followed by selective smelting offered greater recovery of materials by weight (19% metal recycling, 28% total material recycling and 31% recycling/recovery) as well as the widest variety of materials recovered.[26] By May 2016, 100,000 Fairphones were in circulation offering users options to maintain, repair and extend the lifespan of their products. In 2016, Apple sold over 200 million iPhones, taking a large slice of the global smart phone market, with Samsung selling a similar volume. This comes with some responsibility for aiding the recovery of materials used for the phone assembly.

So far, Apple have developed their own R&D project called Liam focusing on the development of a robotic iPhone 6 disassembly line.[27] The system consists of 29 robots in 21 cells with dual-robots used in cells that require more time-consuming disassembly tasks and longer cycle times. The system can recover the cover-glass assembly, lithium battery, motherboard, receiver, speaker, alert module, rear facing camera, and main housing.

There are currently two Liam systems, one in California and another in the Netherlands, each capable of disassembling up to 1.2 million iPhones a year. As Liam is currently an R&D project, the next challenge for Apple and the wider technology industry will be to pilot a product return and automated disassembly and materials recovery process like this, so it can be refined, optimized and implemented at scale.

Right:
The Fairphone with rear transparent cover. The design encourages users to replace and update individual components.


YOURS TO OPEN.
YOURS TO KEEP
FAIRPHONE
© Fairphone

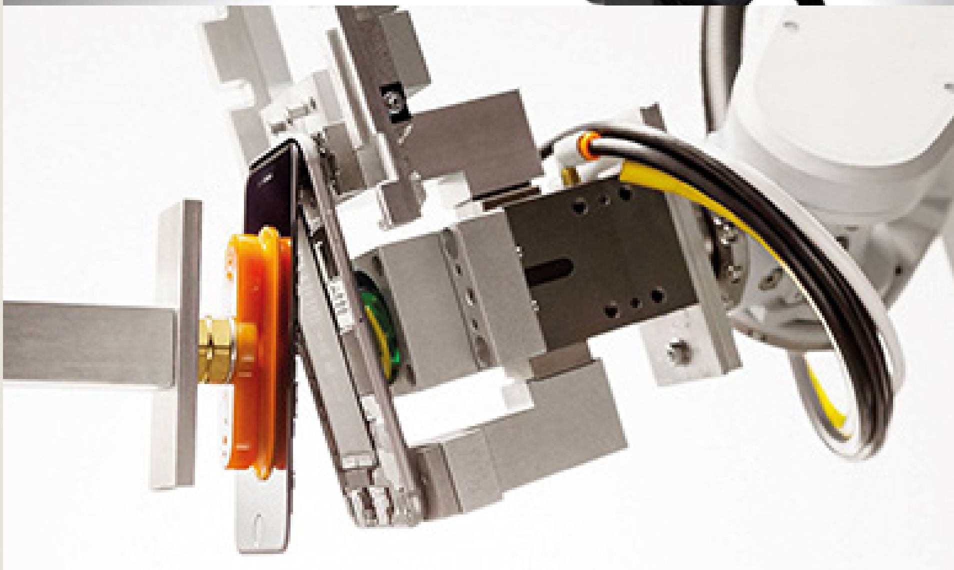


The Success of E-Bay.

Disassembly, recycling and upcycling are not the only solution as we know that one person's waste is another person's treasure. So, perhaps the most useful and successful large scale circular economy initiatives to harness digital technology and the world-wide-web is EBay. Initiated by Pierre Omidyar in 1995, this multinational e-commerce site allows individuals and businesses to buy and sell a plethora of used and new products. Used products, vehicles, toys, clothes, furniture and other products are sold in online auctions for reuse. Specialist products are often sought and despite the controversy that has arisen over certain items put up for bid (entire countries have been listed, often as a joke or to garner free publicity) in general, the company removes auctions that violate its Terms of Service agreement.[28]

EBay offers a new mode of trading products for 162 million active buyers globally, extending the lifespan of those products and offering a greater product choice for consumers. It's hard to think of a more successful realization of the circular economy, one that utilizes and manages data via our ever-developing digital products. Our challenge is to implement a materials recovery infrastructure and refine the design of technology products to enhance recovery. Global and local policy that encourages material harvesting and recovery supply chains will be paramount.

So far, Apple have developed their own R&D project called Liam focusing on the development of a robotic iPhone 6 disassembly line. The system can recover the cover-glass assembly, lithium battery, motherboard, receiver, speaker, alert module, rear facing camera, and main housing.



Left and Right:
The success of Ebay; **Apple's** Liam phone disassembly robot © Apple

PACKAGING
WHAT GOES AROUND COMES AROUND

To understand the magnitude of change in packaging and how recently this change has happened, it is important to understand the history and context of how we got to where we are today and to learn from it. For the movement and protection of food and possessions, we can assume that containment was necessary for early hunter gatherers and their journey out of Africa as early as 50,000 B.C.

Image:
19th Century Birchbark Mocock from East America. Birchbark is simultaneously light, sturdy and waterproof: as a result, it was used to make containers for liquids, such as this mocock for collecting maple syrup. © The British Museum

The lack of any physical remnants from this period could be down to the materials used for such early forms of packaging. The leaves and animal skins used for wrapping, the nut shells and gourds used for water containment, the timber used for storage and movement of larger items and the vines used for strapping and tying them would have naturally decomposed within a few seasons of their initial creation and use.

While early man would have sought solutions to make food transportable later civilisations needed vessels to store as well as transport food. Wooden, ceramic, glass and metal vessels were developed over time with the discovery of new and increasingly sophisticated processes and materials. However, these containers were not packaging in the way we think of it today – they were valuable objects in their own right – used and reused many times.

The idea of storing and transporting food safely in disposable containers was first developed in 1809 when Napoleon Bonaparte offered a 12-thousand-franc reward for a solution to protect and transport food for his armies. Nikolas Appert from Paris placed the food in glass jars, sealed them with cork and sealing wax and placed them in boiling water to sterilise and preserve the food. A year later, food merchant Peter Durant was granted a patent for the pressed cylindrical tin can. Aluminium versions of the can were developed in 1959.

Mulberry tree bark was used in China in the 1st and 2nd centuries B.C to wrap food and the technique of using fine wood and plant pulp for paper making was thought to have started around 1500 years ago for calligraphy and wrapping. Paper making techniques spread globally and improved during the following 1500 years via the Middle East to Europe and America. The first commercial cardboard box was produced in England in 1817, 200 years after China developed corrugated cardboard, replacing wooden boxes for exporting goods. These developments led to cardboard and paper as the most popular packaging material of the 20th Century.

The Rise of Plastic Packaging.

The first known plastic was discovered by Alexander Parker in 1838 and was displayed at the Grand International Fair in London in 1862. This plastic was intended to replace ivory and was dubbed “parkesin”. In 1849 Charles Goodyear and Thomas Hancock developed a procedure that destroyed the sticky property and added elasticity to natural rubber and by 1851 hard rubber or “ebonite” had become commercially available.

In 1870 New Yorker John Wesley Hyatt was given a patent for “celluloid” produced in high temperatures and pressure with a low nitrate content. This invention was the first commercialized plastic and remained as the only plastic until 1907 when Leo Hendrik Baekeland produced “Bakelite”.

The material ingredients of plastic were relatively unknown until 1920 when chemist Hermann Staudinger concluded that plastics, rubber and cellulose materials were ‘polymers’ or substances with a molecular structure, built up from a large number of similar units bonded together. Staudinger and his peers gathered and developed further evidence to back up his theory and 33 years later in 1953, he won the Nobel Prize for *“his discoveries in the field of macromolecular chemistry”*.

With the growth of the global consumer goods market and its need for efficient, low cost, robust and consistent packaging, all with different shapes, colours and branding, polyethylene packaging became more widely used after 1950s. Towards the end of 1970s the plastic packaging sector grew rapidly.[29]

The reason we use so much disposable packaging is its low cost to manufacture from scratch. However, the useful lifespan of a blow moulded plastic bottle is just 2-3 weeks, whilst the useful lifespan of a plastic bag is just 12 minutes. After it’s all too brief life, plastics such as polyethylene terephthalate (PET) takes 50 to 100 times longer to biodegrade compared to the cellulose fibre plant based materials that were widely used before the 20th century. Now, around 300 million tons of plastic is produced globally each year. Just 12-14% of that is recycled. Much of this plastic packaging waste finds its way into the ocean and it is estimated that 5 trillion tons of micro plastic are in the oceans now with one truck load added each minute. There are a multitude of initiatives that can reduce plastic packaging waste and reverse this trend. Glass and plastic bottle return schemes run successfully in Germany, Denmark and some states in Australia and the USA. The UK’s 5p mandatory charge for plastic bags implemented in 2016 saw an 85% reduction in the disposal of plastic bags, resulting in a sharp increase in bag reuse that customers bring to shops

Plastic that has not been co-moulded with another polymer or over moulded around other materials such as metal are very recyclable as is paper.

We developed a biodegradable packaging design that allows efficient delivery, display on the shelves and a cup that provides easy handling and eating of the porridge.

However, the paper coffee cup is a waste stream that is often assumed to be recyclable. A conservative estimate puts the number of paper cups handed out by coffee shops in the UK at 3 billion, more than 8 million a day. Yet, fewer than one in 400 cups are being recycled. The problem stems from the materials used for the cup. It is manufactured from paper laminated with a plastic layer, to keep it water or coffee tight. But the compound creates a complicated recycling process. It cannot be viably treated as pure paper. First, the plastic coating needs to be separated from the recyclable paper fibre of the cup itself.

Jonny Hazell of Green Alliance summarized. *"There's a real challenge to separate compound materials"*.[30] To solve this problem, reusable ceramic cups could be used by customers in the coffee shops, whilst coffee to go could be supplied in a re-usable coffee cup that the consumer pays for and can be cleaned in the office or at home ready for reuse.

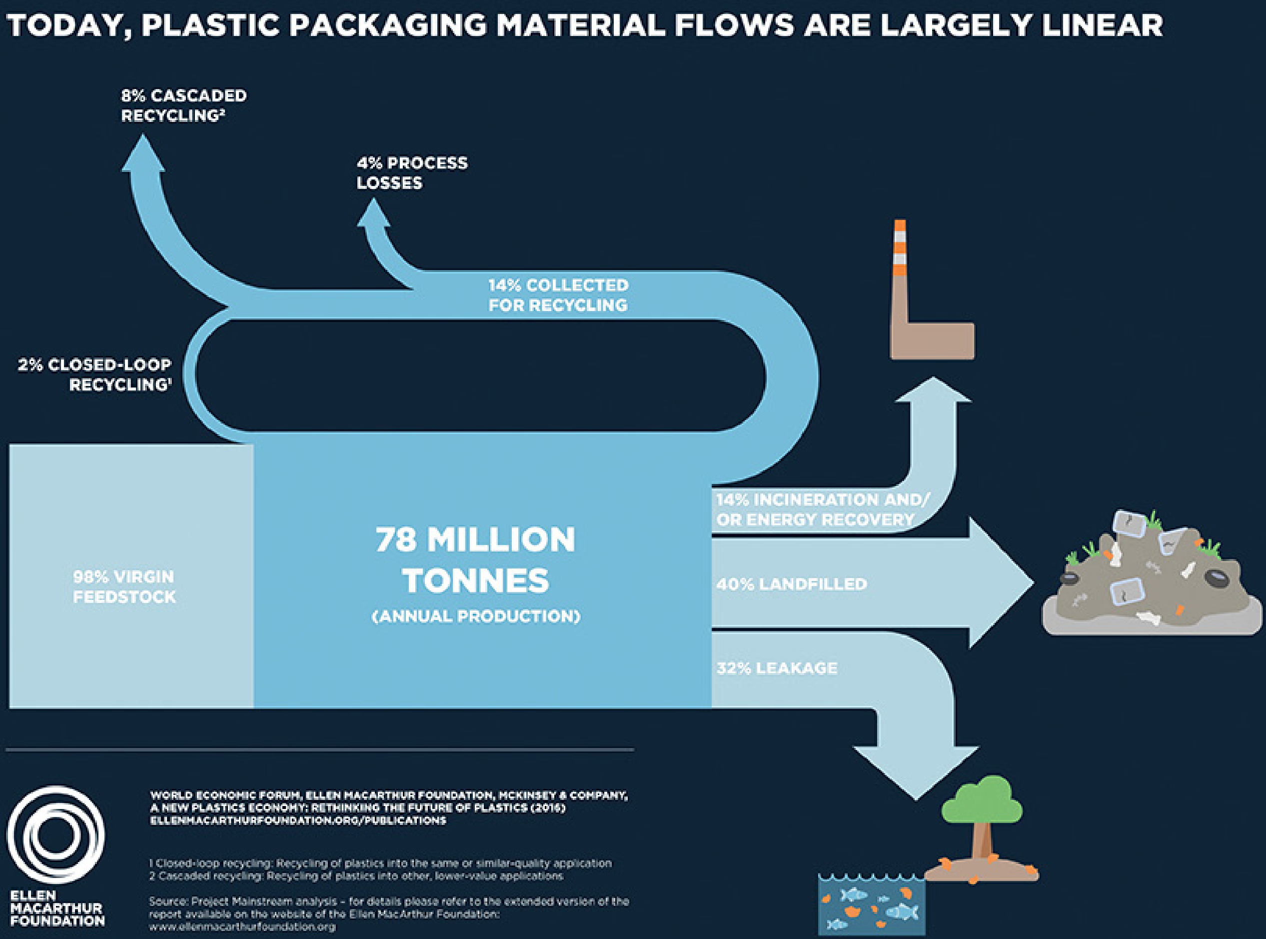
Compostable Packaging.

Another potential solution to reduce packaging waste is to revert back to the simple cellulose or plant based compostable packaging materials used by our ancestors some 50,000 years ago. Skaertoft Mølle is a small-scale organic mill, situated on Als, an idyllic island off the southeast coast of Denmark. Owned and run by Jørgen Bonde and Hanne Risgaard, they realised that farming organically "just wasn't enough" and they decided to produce baking ingredients that were out of the ordinary. Since 2003 they have specialised in the production of organic, freshly ground flour with bran and preserved wheat germ, especially suited for artisan bread-making. They grow and source low yielding grain varieties that provide the highest quality. *"The flour is stone ground to preserve the natural content of vitamins, minerals and amino acids that are so important to us."* [31]

It is this desire to maximise the goodness and flavour of the products in a sustainable way that led them to approach Arup for materials advice and the design of the packaging that contains the same DNA as the healthy and sustainable porridge ingredients they were developing. We developed a biodegradable packaging design influenced by the Danish modern design masters Arne Jacobsen and Hans Wegner that allows efficient delivery, display on the shelves and a cup that provides easy handling and eating of the porridge. The cup, lid and sleeve are designed and engineered using natural cellulose fibres derived from sugar cane. This cellulose material can be disposed of as food waste and follow the same anaerobic digestion or in-vessel composting process applied to food waste streams.

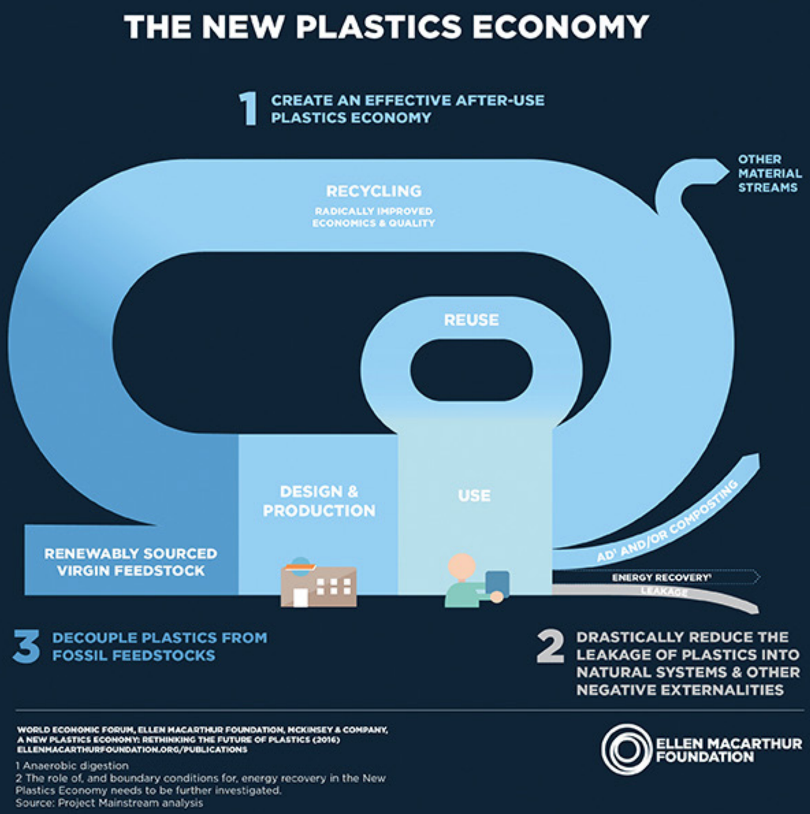
A move away from plastic packaging that takes decades or centuries to degrade, to faster degrading non-laminated paper and card packaging and compostable cellulose based packaging makes sense. Polylactic acid (PLA) is a bio plastic produced from corn or dextrose. Its characteristics are similar to conventional petrochemical-based mass plastics such as polyethylene terephthalate and it can be processed using standard equipment that already exists for the production of some conventional plastics. PLA and PLA blends generally come in the form of granulates with various properties, and are used in the plastic processing industry for the production of films, fibres, plastic containers, cups and bottles. The challenge with these materials is strength, however for a use once solution, a container that is biodegradable via industrial composting could make more sense than a single use container manufactured in super durable plastic that degrades in the ground or ocean over several centuries.

Left: **Compostable packaging** by Arup for Skaertoft Mølle



The New Plastics Economy.

The poor recycling rates of plastic packaging was the primary theme at the World Economic Forum (WEF) in Davos. In 2016, The WEF and Ellen MacArthur Foundation launched 'The New Plastics Economy' initiative and publication [32] highlighting the need to prioritise plastic recycling and reuse rates globally and the need to prevent waste plastic ending up in the oceans.



The initiative included calls for

- Innovative packaging models based on product refills and replacing single use plastic bags with reusable alternatives, which could see 20% of plastic packaging profitably reused.
- A further 50% of plastic packaging could be profitably recycled if improvements are made to packaging design and systems for managing it after use.
- A fundamental redesign and innovation in small format plastic packaging such as sachets, tear-offs, lids and sweet wrappers which represent 30% of the market by weight and often escape collection systems.
- Replacement of three uncommon polymers which are used as packaging materials globally, but in comparatively small volumes: polystyrene (PS) expanded polystyrene (EPS) and polyvinyl chloride (PVC).

The Ellen MacArthur Foundation's call to the plastics and packaging industry and to relevant policy makers is to coordinate and create an improved recycling and effective after-use, plastics economy that encourages the reuse of existing material.

"It's simply never going to be economic to sort out all the millions of plastic items disposed of every day into all the thousands of grades, let alone recycle them all separately."

Due to the sheer volume of plastics on our planet and disposed of today, designers and engineers will need to master how to better use all the different types of plastics as a valuable material resource. Graham Dodd, who leads Arup's global Materials team points out that engineers have the opportunity and duty to imagine how something could be better and to make it so.[33] Over the years he has designed all sorts of things out of glass but started his career designing domestic appliances, long before joining Arup. For him, engineering is about designing and making useful things out of materials, using innovative processes. He leads the materials practice where they focus on the materials and manufacturing knowledge used by our designers for the built environment *"making materials work' is how I sum up our purpose."*

He would like to see society master its use of materials and processes so that we can develop in harmony with our environment and believes that the great advantage of plastics is their diversity of types and properties. Sadly, as he points out, this is also the biggest obstacle to recycling them. *"It's simply never going to be economic to sort out all the millions of plastic items disposed of every day into all the thousands of grades, let alone recycle them all separately."*

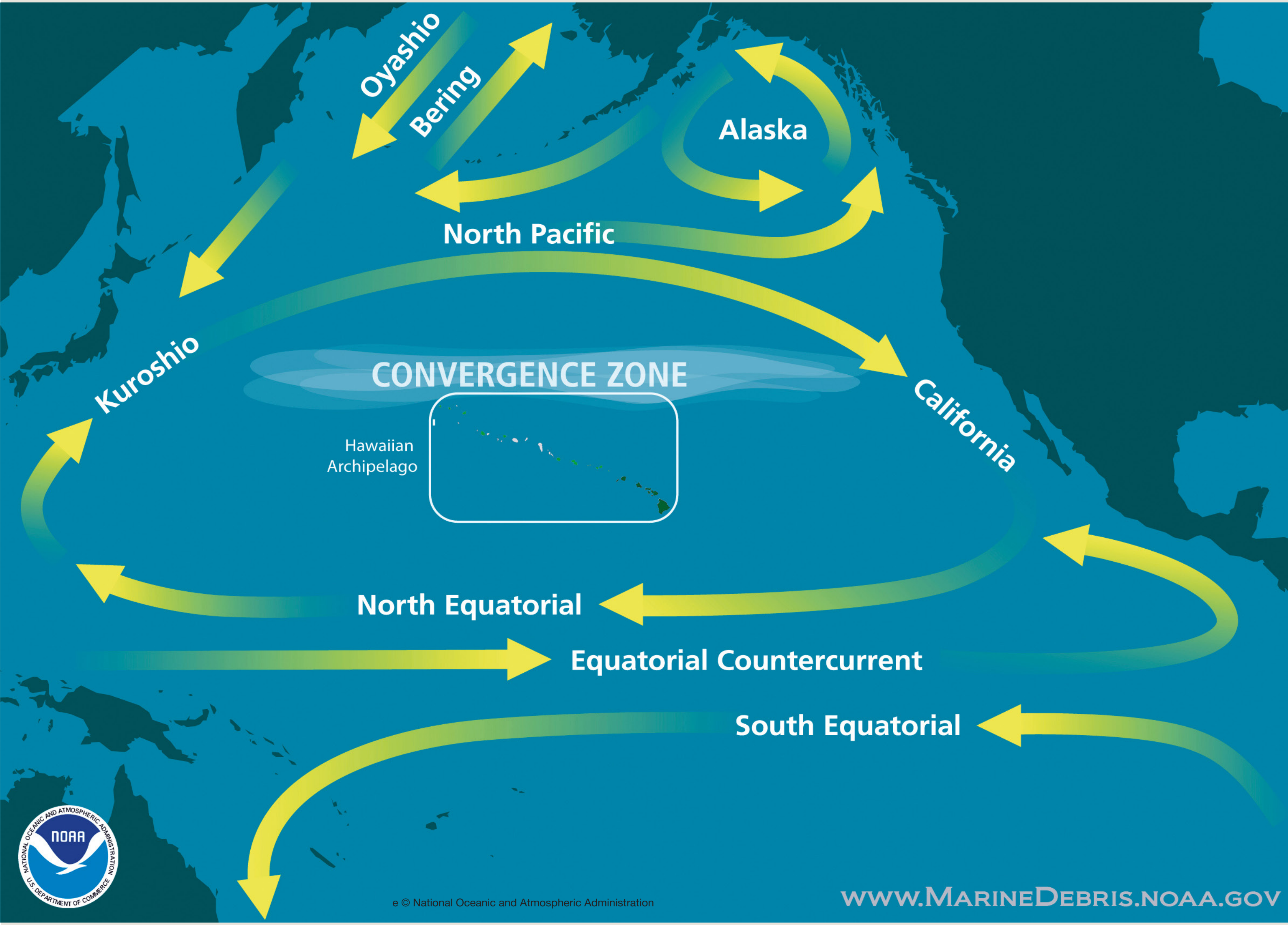
However, he also believes that if we can make something useful out of this mixed waste, using low capital investment, it will become worthwhile to salvage it. Not only will this rescue plastic from landfill, but it will also give us the chance to unlock valuable polymers. At the end of their life, the re-made plastic objects could be depolymerised into a petroleum form, from which speciality polymers can again be made.

There are emerging processes that can make useful, comparatively low-performance products out of mixed plastic waste. The key is designing with this type of material in mind. It tends to produce objects with thick wall sections and the control of structural properties is not very precise. But it can be perfectly good for transport pallets, site hoarding, railway sleepers, work boats, barge covers and hundreds of other applications that are yet to be found.

Designing products for this class of material and their manufacturing process is an area few people are yet working in and it needs some adjustment from the usual methods for designing in plastics. At Arup, Graham Dodd and his team have been working with one such technology, the powder impression moulding (PIM) process, and have learned a great deal from designing a stadium seat in this way.

If we can think of plastics as having this sort of two-stage life cycle, it gives a glimmer of hope for solving the issue of plastic debris in the ocean, which the United Nations Environment Programme (UNEP) has described as a "wicked problem". The quantity of floating plastic debris is estimated in the hundreds of millions of tonnes.

Image: North Pacific Gyre convergence zon


Oyashio
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North Pacific
Kuroshio
CONVERGENCE ZONE
California
Hawaiian
Archipelago
North Equatorial
Equatorial Countercurrent
South Equatorial
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
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www.MarineDebris.noaa.gov

"That scale of material sounds like a resource to me, so what useful things could be made from salvaged marine plastics using PIM or other mixed plastics processes."

He has also considered how could we collect the plastics for processing? The plastic in the oceans accumulates along the high-water mark and in a number of regions known as gyres. The largest of these is the North Pacific Gyre, (also known as the Eastern Garbage Patch). *"Is a resource like this worth trawling for? Before long, someone will find a way to make it economic to collect this debris and make a useful thing that pays for itself and eventually is desirable for de-polymerisation and re-synthesis. In the meantime, one class of plastics that stands out and to a limited extent is already being selected and recycled is polyethylene terephthalate (PET)."* [33]

Known as polyester in fibre form and PET in blow-moulded bottle form, these plastics are very easily recycled into products of near enough original quality. Perhaps the most popular PET product example is the soft drinks bottle, where at least one company sells some of its product in bottles made from recycled PET.

At the 2017 WEF, Unilever announced that all its plastic packaging would be fully reusable, recyclable or compostable by 2025.

Proctor & Gamble launched a shampoo bottle consisting of 25% recycled post-consumer plastic beach waste. They announced that by the end of 2018, 90% of its European production of Head & Shoulders and Pantene packaging will consist of 25% beach waste, equating to 2600 tonnes of recycled plastic each year. Other global signatories, committing to the initiative were Amcor, Carrefour, Coca-Cola Co, Constantia Flexibles, Danone, L'Oreal, Marks & Spencer, Mars, Pepsico, Veolia and Dow Chemicals.[34]

Packaging Re-use and the Future.

But plastic packaging isn't the only problem. Glass drinks bottles are wholly recyclable into new bottles as contamination from other materials is low, however the glass re-processing at the molten end of the bottle manufacturing process requires natural gas or fuel oil-fired furnaces operating at temperatures of up to 1,575 °C. The glass recycling industry is relatively well developed, however as 1.4 kg of CO_2e is required to re-manufacture 1kg of recycled glass and 8.4kg of Co_2e is required to re-manufacture 1kg of non-recycled glass, bottles that are used only once seems energy intensive.[35] A recent Life Cycle Assessment from the The Institute for Energy and Environmental Research in Germany showed that refillable bottles have 50-60% lower global warming potential than single use bottles.[36]

Pre-1990s, drinks in Germany were often bottled in refillable glass and plastic containers. The customer paid a small deposit as security, ensuring they would return the bottle intact, to receive their deposit back. The retail price of the drink included the cost of returning the bottle to the beverage supplier and the cleaning, re-filling and return process. During the 1990s, retail price competition resulted in cheaper, single use packaging as a more popular choice with Germany's refillable quota falling below 72% for the first time. This triggered a return to a mandatory deposit system in 2003. This successful u-turn has resulted in over 90% of refillable bottles being returned by consumers. The durability and quality of the recovered materials is good enough for glass and to a lesser extent plastic bottles to be reused several times before glass recycling becomes necessary. Similar deposit systems have proved successful in all Scandinavian countries, Holland and Croatia.

In the U.S, ten states have passed container deposit legislation, popularly known as 'Bottle Bills' to increase glass and plastic recycling rates and reduce litter. Studies show that beverage container legislation has reduced roadside litter by between 30% and 64% in states that have passed the bill and while overall beverage container recycling rate is approximately 33%, states with container deposit laws have a 70% average rate of beverage container recycling. Michigan's recycling rate was the highest in the nation, as was its $0.10 deposit.

Left and above: **Beach** waste; **Recycled** plastic polymers out of PET water bottle; **Shampoo bottle** made from 25% plastic beach waste.

Taking a pathway towards a more sustainable and robust packaging future is challenging but necessary. We will continue to need a mix of different packaging types and materials, some recyclable, some reusable and some compostable. The following suggestions provide guidance in how to start the journey to a more sustainable packaging future.

Ellen MacArthur Foundation's 'New Plastic's Economy' publication provides an in-depth guide to the current issues around plastic packaging. The key aims I found particularly important were as follows:

- Radically increase the economics, quality and uptake of recycling.
- Scale up the adoption of reusable packaging.
- Scale up the adoption of industrially compostable plastic packaging for targeted applications.
- Improve after-use collection, storage and reprocessing infrastructure in 'high-leakage' countries, where materials often fall out of the recycling system.
- Steer innovation investment towards creating packaging materials and formats that are easier to reuse and recycle. Reduce reliance on laminated or multilayer plastics and papers that are virtually impossible to recycle.
- Decouple plastics from oil based feedstocks.
- Establish the global plastics protocol with clear and coordinated material labelling.
- Engage policymakers to develop legislation that encourages these aims.

The plant based materials used for packaging by our early and more recent ancestors left a small foot print on our planet. Timber derived cardboard and paper remains as a low impact, recyclable material that can be enhanced with a proportion of renewable virgin timber fibre. The development of re-usable or recyclable alternatives to the laminated plastic films and containers should be a primary goal. This, combined with improved reuse, return and recycling initiatives, regulated by policy development, legislation and education will be necessary to harmonise our packaging industry and economy.

Image: **Reverse** vending machines


PLASTIC PACKAGING IS PRESENT THROUGHOUT OUR EVERYDAY LIFE
1
PET
Water and soft drink bottles, salad domes, biscuit trays, salad dressing and peanut butter containers
2
HDPE
Milk bottles, freezer bags, dip tubs, crinkly shopping bags, ice cream containers, juice bottles, shampoo, chemical and detergent bottles
3
PVC
Cosmetic containers, commercial cling wrap
4
LDPE
Squeeze bottles, cling wrap, shrink wrap, rubbish bags
5
PP
Microwave dishes, ice cream tubs, potato chip bags, and dip tubs
6
PS
CD cases, water station cups, plastic cutlery, imitation "crystal glassware", video cases
6
EPS
Foamed polystyrene hot drink cups, hamburger take-away clamshells, foamed meat trays, protective packaging for fragile items
7
OTHERS
Water cooler bottles, flexible films, multi-material packaging
WORLD ECONOMIC FORUM, ELLEN MACARTHUR FOUNDATION, MCKINSEY & COMPANY,
A NEW PLASTICS ECONOMY: RETHINKING THE FUTURE OF PLASTICS (2016)
ELLENMACARTHURFOUNDATION.ORG/PUBLICATIONS
Source: Project MainStream analysis
ELLEN MACARTHUR FOUNDATION

CONCLUSIONS

We all need physical things to conduct and live our everyday lives. Packaging to contain and transport food and products safely, utensils to prepare and eat the food we need, modes of transportation to get from place to place, a multitude of tools and devices from beam-saws to smartphones and taps to toothbrushes to carry out our day to day activities. We need buildings to provide shelter and furniture, light, heat and ventilation provide further levels of comfort. All these things have allowed people to thrive and say something about our beliefs and culture.

> ...these materials are not infinite, the design, material conversion and assembly processes required to make, re-use, recycle and upcycle these things needs a refinement or change in approach.

However, all these things are made from materials that are extracted from the ground or grown and may need energy to power them. Because these materials are not infinite, the design, material conversion and assembly processes required to make, re-use, recycle and upcycle these things needs a refinement or change in approach.

The research described in The Industrial Resolution demonstrates just some of the exciting opportunities and challenges that closed loop design, material re-use and product re-manufacturing presents today. A look at the past shows that products and utensils were not replaced every 18 months, superseded by the latest trend. A continued shift towards the adoption of products that people value more, both physically and aesthetically, which last longer, is essential.

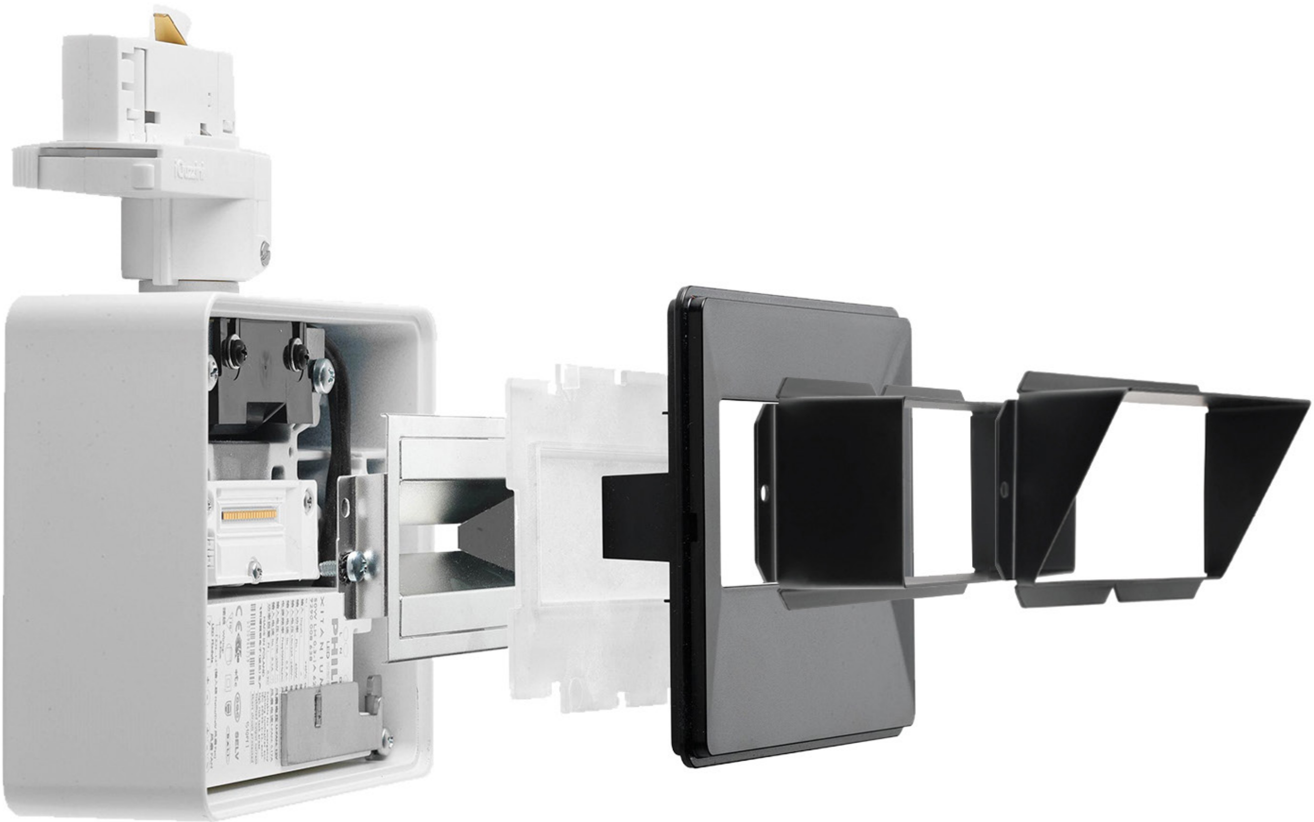
Products that avoid short term technological and stylistic trends tend to endure as they don't 'date' as quickly; contrasting perhaps with smart phone upgrades that result in an operational life that's shorter than an item of clothing. We need to treat all materials as a precious resource.

To ensure a product is useful and usable in the first place, designers, engineers and manufacturers need to consider the user at each phase of the design development process. Products have to look right and bring excitement to be accepted by people in the first place. They need to work perfectly, long term, and we need to offer more product refurbishment, part replacement and take back schemes as a service and to harvest materials from products that have reached the end of their useful lives. Moving forward, the design of ingenious and desirable new products that re-use waste material as a resource that can, in turn, be recycled is our key challenge. If we get it right, and we get the message across to a new generation of consumers, they will increasingly value this approach and it will strengthen their loyalty to certain brands and manufacturers.

This approach, combined with robust, re-usable packaging and the increased use of natural, cellulose based, biodegradable packaging will further reduce contamination of land and water.

The use of dry fitted, removable screws, clips and snap fittings as opposed to adhesives and resins to connect different base materials will ease material separation and harvesting in the future. Products will then be easier to repair and refurbish, thus extending life span and will allow material and component separation at end of life.

Our recent dependence on low value, cheap products can be seen as one of the primary causes of our disposable culture that generates so much waste. The products we use should not necessarily be super expensive, but high value, high performance, robust, beautiful and user friendly items, something to be proud of, cherish and age beautifully, products that need less energy to make and use should be an aspiration for us all.



© iGuzzini

Above: **Arup and iGuzzini designed View,** a versatile family of high performance, low energy LED lighting for museums, art galleries and retail. Use of clips and screw fixings allow hardware replacement and material separation at end of life.

We have seen that there are plenty of opportunities to upcycle, reuse and recycle on a range of scales from quirky furniture reassembly by Carl Clerkin, Goldfinger Factory's upcycled products made from waste material, Pop-up Repair's product refurbishment services in New York and on a larger scale, Novalis' and Jaguar Land Rover's development of cars that use increasing volumes of recycled aluminium and the success of E-Bay.

"We need to make products, buildings and vehicles that are 'closed loop' that reuse waste material, last longer, allow repair and reuse and allow materials and parts harvesting at the end of their useful lives."

Sir Kenneth Grange

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CREDITS

The Industrial Resolution
Written by Stephen Philips.

Contributors:
Sir Kenneth Grange
Carolina Bartram
Neil Perry
Josh Treuhaft

Art Director: Liz Dunford
Proof-Reader: Heather Clements

Thanks to:
Devni Acharya
Lucie Barouillet
Jørgen Bonde
Richard Boyd
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Rod Fountain
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