The Little Book of CIRCULAR ECONOMY in cities

A Short Guide to Urban Metabolism and Resource Flows

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Contents

What this little book tells you

Cities are complex systems whose quality, efficiency and resilience cannot be addressed solely as economic issues.[1] This little book has arisen out of work carried out as part of the Liveable Cities research programme. To help in understanding more fully how a large UK city operates, data were collected on Birmingham city's resource flows and waste from 2012/13. This case study of a major city will help to illustrate the following core ideas in the book, which include the following:

- Problems in cities related to resources and waste.
- Urban Metabolism (UM) is a useful decision-making tool that has both benefits and shortcomings.
- The current consumption system has a few failures that need fixing.
- Research on UM in Birmingham gave us an insight into what flows in, out and around the city.
- The Circular Economy (CE) and its framework might be a way to improve upon the current consumption system.
- Two industry examples – mobile phones and beer – give us some good ideas about business models that work well in terms of implementing CE principles.

[1] Government Office for Science. Urban metabolism: a review in the UK context. 2015 Available at: www.gov.uk/government/publications/future-of-cities-urban-metabolism

Introduction to Urban Metabolism and Circular Economy

We are currently living in an era of constant change and urban growth. We recently reached the point at which more than half of the world's population is concentrated in cities and urban areas. This many people living in cities is a consequence of several factors; but perhaps the most important is the migration of people from rural to urban areas.

Over time, cities have expanded so much that they have absorbed the small towns near them, or conversely several cities have merged into a single metropolitan zone. Furthermore, cities have developed a high dependency on their surroundings, specifically for the supply of resources and the disposal of waste.

Besides urban population growth, the increase in average income in both developed and developing countries has resulted in a growing middle-class, which is demanding more products and services.[2] To meet this growing demand, an increasing volume

[2] McKinsey Global Institute. Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs, McKinsey Sustainability & Resource Productivity Practice, 2011.

of raw materials is being extracted globally (flowing into the city), producing large amounts of waste (flowing out of the city) in the process.[3] These flows require careful consideration for current and future city generations.

Research to address this has been referred to as Urban Metabolism (UM); it is an important concept in this respect where cities are conceptualised as a living and breathing organism. The term was originally used by Abel Wolman in 1965,[4] and has been developed and adopted by different disciplines to study different aspects of a city's operation and performance. UM offers a technique to identify, describe and measure city flows that can provide city planners and politicians, as well as citizens, with information to aid decision-making that make cities (more) liveable.

There are varied diverse arrays and quantities of flows (and accompanying interactions) that occur in, around and outside of a city. These flows include, but are not limited to:

1. FLOWS IN – resources (metals, plastics, timber, fuels, food, water, etc.);
2. FLOWS OUT – manufactured products, but also solid, liquid and gas wastes. These include, for example, municipal solid waste, waste water, and atmospheric pollution (from carbon dioxide emissions).

As resources flow through a city, they are treated / processed in order to provide clean water, food, heat and power for inhabitants to survive and thrive, for example through the creation of roads, buildings and other city infrastructures that are so essential to 21st Century civilised life. UM refers to these physical structures as stocks, analogous to the bones and flesh of a set of biological defined organisms.

To date, UM[5] has played an important role in understanding the sustainability of

[3] Leonard A. The Story of Stuff: How our obsession with stuff is trashing the planet, our communities, and our health – and a vision for change. 2008. Constable and Robinson Ltd., London, UK.

[4] Wolman A. The metabolism of cities. *Scientific American*. 1965; 213 (3) 179-190.

[5] You can find more information about Urban Metabolism from the following authors: Kennedy, C.; Cuddihy, J.; Engel-Yan, J. The changing metabolism of cities. *Journal of Industrial Ecology*. 2007, 11 (2), 43–59. Pincetl, S.; Chester, M.; Circella, G.; Fraser, A.; Mini, C.; Murphy, S.; Reyna, J.; Sivaraman, D. Enabling future sustainability transitions: an urban metabolism approach to Los Angeles. *Journal of Industrial Ecology*. 2014, 18 (6), 871–882, and in *Resources* at the end of this book.

cities, not least because it involves the calculation of how many resources are used, how much waste (including carbon dioxide emissions and other greenhouse gases) is generated and how many stocks are accumulated by a city. As such, a UM approach to cities has the potential to provide a very useful framework for designers to understand how to develop low carbon neighbourhoods through a synthesis of flows. It can also help urban retailers and consumers to understand where their resources come from, but more importantly, to recognise where their waste goes to.

Circular Economy (CE) is an important concept in this respect, not least because its underlying philosophy is the elimination of waste within the consumption system – in this specific case the city. For example, it supports the (re)use of waste as a resource for other production activities by a process that is more commonly referred to as Industrial Symbiosis (IS), it is an important aspect of UM, since it fosters cooperation between industries to identify where a waste outflows or by-products from one industry can be used as a resource inflow (or feedstock) for another.

However, CE has far more to offer than what we have outlined thus far. Operating within these highly (inter)dependent urban system-of-systems, CE necessarily has a very broad definition as suggested by Kirchherr et al:[6]

> *"an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/ distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers."*

As such, there appears to be significant merit in supporting an approach to cities that combines UM and CE. At the University of Birmingham, such an approach – the *Liveable Cities Method* – has been developed to help improve not only urban

[6] Kirchherr J.; Reike D.; Hekkert M. Conceptualising the Circular Economy: An analysis of 114 definitions. Resources, *Conservation & recycling*. 2017. 127, 221-232.

sustainability but also the liveability of its citizens.[7] In parallel, city performance has been assessed so as to act as a way to help city decision-makers[8] understand the consequences of their policies and actions.

[7] Leach, J. M, Rogers, C.D.F., Locret-Collet, M., et al. 2017 (submitted). A decision-making method for enhancing urban sustainability and liveability. *ICE Cities of the future - Special Issue* 2018

[8] Leach, J. M, Lee, S.E., Hunt, D.V.L., Rogers, C.D.F., Improving city-scale measures of liveable sustainability: A study of urban measurement and assessment through application to the city of Birmingham, UK. *Cities*. 2017; 71, 80-87.

Our current Urban Metabolism: a linear approach

In general, cities demand vast amounts of food, energy, water and materials to satisfy the needs of their citizens. Cities also need to deal with the waste generated from disposal and from all the production stages. Many problems arise when our (re) sources for materials and energy are being depleted at an ever-increasing rate. We also find ourselves living in an ever-more polluted environment.

Why is the current consumption system flawed?

A major challenge for sustainability is the ever-increasing demand for products and services, caused by the growing population and a middle-class being able to afford more goods. The intensive manufacturing of products can be traced back to the industrial revolution era. This mass production has caused among other things: serious concentrations of air pollution including the increasing levels of carbon dioxide (CO_2) in the atmosphere, depletion of soil fertility, deforestation and over-exploited water sources. In other words, we are exhausting the planet's resources and accumulating mountains of waste while doing it.

The current consumption system is based on these six stages:

1. Raw materials are extracted from the Earth's crust
2. These raw resources are refined to be ready to use
3. Parts, components and pieces are created by processing the materials
4. Products are formed from the assembly of the components
5. The final good is used for a limited amount of time
6. When the product reaches its "end-of-life", it becomes waste and we get rid of it.

However, waste is generated at every stage of the process, not only at the end. Additionally, all stages require energy, cause pollution and generate CO_2. On top of that, some products keep polluting when in operation, for example cars, gas boilers and such like. Once the product expires, the process is reactivated from scratch. This failing system of consumption is called Linear Economy (LE). In other words, we extract to throw away.

Urban Metabolism: of Birmingham and its Hinterland

To understand UM more fully, it helps to have a real-world example. Researchers at the University of Birmingham have investigated the UM of Birmingham, the outcomes of which are described briefly below.

The Birmingham context

Since the 16th century, the city of Birmingham has changed from a market town, to an intensive industrialised and manufacturing trade centre, and now in the 21st century to a service-oriented ambitious city. Birmingham is currently acknowledged to be an important European shopping and convention centre. Its population is nearly 1.1 million people and around 6 million live in a 50-mile radius. In terms of ecological urban fabric, the city has 6 million trees and more parks than any other European city of equivalent size.[9] In terms of further education Birmingham is home to four

[9] Loat, S. Birmingham – Stuff You Should Know! Available online: http://tinyurl.com/4qbtz7 (accessed 15 August 2017).

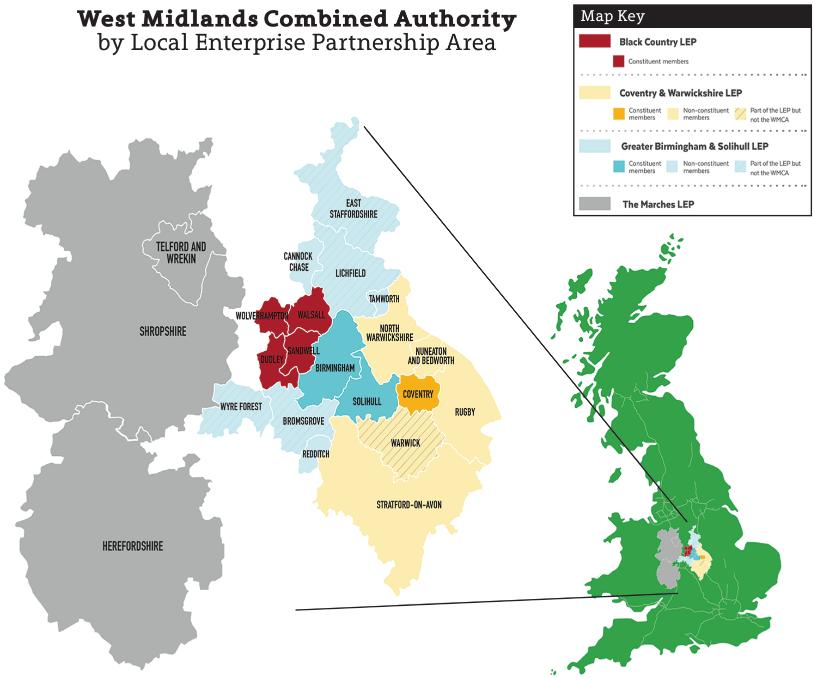

Figure 1. West Midlands Combined Authority Map Source : https://www.blackcountrylep.co.uk

universities and several colleges. Despite its prominence, the city faces many social challenges. For example, there is high social deprivation in inner city areas,[10] the total unemployment rate is 8% (compared with 5% in England)[11] and more than a quarter of adults are obese (the third highest in the UK).[12]

Cities can be thought of as regions where the transformation and consumption of resources takes place. However, many of these resources are located outside the city, in their hinterlands. Birmingham's hinterland is formed of three Local Enterprise Partnerships (LEPs), as shown in Figure 1. The criteria defining Birmingham's hinterland are:

1. the area where at least 75% of residents work;
2. the Black Country, the area with historic links to the city and within 20 km distance;
3. Surrounding areas which are characterised as having their economic activities linked to Birmingham.[13]

The Urban Metabolism of Birmingham

Different resource flows were studied to work out how much of each flow existed in terms of mass (kilotonnes). Data were collected from government, utility companies and local sources. Some of these data (e.g. materials) were only available at the regional or national level and therefore had to be adjusted to the city-level by assuming the population in Birmingham consumed at the same rate as the national population. Waste data were collected from studies commissioned by Birmingham City Council. Again, this provided estimates as to the total waste produced by the city. All the flows are shown in Figure 2.

[10] BBC. Index of Deprivation 2010-An Analysis of Birmingham Local Statistics. Available online: https://tinyurl.com/y9x6bsg9 (accessed 13 August 2017).

[11] BBC. Areas of Deprivation. Available online: http://tinyurl.com/y9z76fqu (accessed 15 August 2017).

[12] Centre for Obesity Research Obesity in the UK. Available online: http://tinyurl.com/moxuq7t (accessed 12 August 2017).

[13] Lee, S.E.; Quinn, A.D; Rogers, C.D.F. Advancing City Sustainability via its Systems of Flows: The Urban Metabolism of Birmingham and its Hinterland, *Sustainability*. 2016, 8 (3).

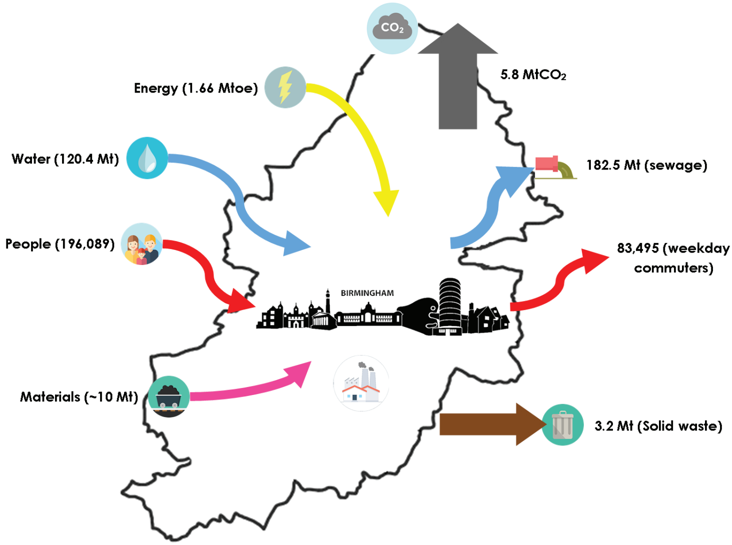

Figure 2. Mass flow analysis for the city of Birmingham (UK) in 2012/2013. Source: Based on Lee et al. (2016).[14]

From Figure 2, it can be observed that a significant amount of energy is consumed by Birmingham (1.66 Mtoe,[15] which equates to 18,608 GWh).[16] This is around 16% of the energy consumed in the West Midlands and just under 2% of the energy consumed by the UK. The city as a whole emits just under 6 million tonnes of carbon dioxide. There is also a large amount by mass of water coming into the city (i.e. 120 million tonnes or 120 Giga litres) that needs to be distributed to peoples' homes as well as to industry. This involves pumping, which again involves using energy. The "people" flow refers to commuters coming into and out of the city on a weekday. The mass of materials imported into the city is approximately 10 million tonnes and the

14 *Ibid*, (note 13).

15 Mtoe – Million tonnes of oil equivalent. 1 toe represents the energy generated by burning one metric ton of oil and is equivalent to 11.63 megawatt hours (MWh)

16 A GWh equals one million kilowatt hours of electricity – enough to power around one million homes in the UK for an hour. For further reference visit: https://tinyurl.com/y8s62vaq

solid waste collected by the Council annually is just over 3 million tonnes.

One of the shortcomings of this approach is that it can only highlight the individual flows rather than the interactions between these flows and the overall impact of these interactions. It also provides a 'snapshot' in time and flows fluctuate on an hourly, daily, weekly, monthly and yearly basis. Future work will build on this snapshot to consider these interactions and their implications for the city and its resources.

Having considered UM, it is important to reflect how the city can extract the maximum benefit from such flows and how it can minimize its waste to enable it to operate in the most efficient and beneficial way for its citizens. To do this, we need to consider the concept of CE. The following section explains this concept in more detail.

Circular Economy: key elements and framework

The Linear Economy (LE) approach assumes that there are unlimited resources and capacity for waste disposal;[17] a statement which is certainly wrong. We live in a world with a finite supply of resources that human beings continue to extract; it is not possible to keep a linear system running indefinitely in such an environment. Kenneth Boulding,[18] in his essay "The Economics of Spaceship Earth", envisaged the future Earth as a closed system, that is, no resources and energy – apart from that received from the sun – coming in or outside the system. With this in mind, circular relationships should be adopted for all its resources within such a system. This is the main pillar of CE and the direct opposite of the approach adopted in LE.

[17] Allwood, J.M. Squaring the Circular Economy: The Role of Recycling Within a Hierarchy of Material Management Strategies. In Handbook of Recycling State-of-the-Art for Practitioners, Analysts, and Scientists, 1st ed.; Worrel, E., Reuter, M.A., Eds.; Elsevier: Waltham, MA, USA. 2014; 445–477.

[18] Boulding, K.E. The Economics of the Coming Spaceship Earth, in Jarrett, H. (Ed.), Environmental Quality Issues in a Growing Economy, Johns Hopkins University Press, Baltimore, MD, 1966. 3-14.

How has CE emerged?

To preserve our valuable resources, we are becoming ever more aware that we need to change the way we consume and waste things. Besides reducing our consumption habits and seeking efficiency, we should also think of waste as a secondary (and even tertiary) resource before finally disposing of it. For example, gardeners are already well-versed in the fact that organic waste can benefit the production of future food crops through nourishment of the soil – a fertiliser.

However, products obtained from non-biodegradable resources require a more complex approach to recycling and re-use. Therein the global understanding of sustainability is changing (and evolving) constantly and the adoption of a more non-linear consumption system (as described hereafter) can and will contribute to shaping the future of our businesses, societies, policies and cities.

For too long, humanity has taken a linear approach towards resource consumption: we take, make, use and dispose. Data from the Organisation for Economic Cooperation and Development in 2015[19] shows that nearly half of the estimated 62 billion tonnes (Gt) of raw materials extracted each year worldwide will not regenerate – they are lost forever. Nearly a quarter of those resources are transformed into 12 Gt of waste. After all these centuries of operating, and observing the deficiencies of the LE, only a third of the waste produced is recycled. However, recycling rates vary widely from developing to developed countries. Furthermore, recycling rates remain high for high-volume materials, like paper, plastics and glass, but are low for several high-value materials, such as precious and rare critical metals, for example, the six platinum group metals (iridium, osmium, palladium, platinum, rhodium and ruthenium).[20] Recycling has been the main solution proposed to closing-loops in the current linear system of consumption. It is worth mentioning that in some countries, there are incinerators that burn waste for energy. Whilst this avoids the need to recycle and landfill, it very rarely, if ever, closes the loop. Moreover, it raises issues of potentially releasing harmful gases into the atmosphere and creating residual waste. Although, where energy is extracted, compelling arguments can be (and are) made for its adoption – not least in Birmingham … and a number of other UK cities.

19 OECD. Material Resources, Productivity and the Environment: Key Findings, Green Growth. 2015. Available online: https://tinyurl.com/y9lh5yj7 (accessed 21 August 2017).

20 *Ibid*, (note 19).

Whilst helpful, recycling on its own is not enough. Annie Leonard (2008) gives two main reasons for this. Firstly, household waste is only a small part of all the waste generated after the consumption process. Waste from transportation, energy, chemicals and water usage is not considered. Secondly, most of the waste is not easily recyclable, mainly because it has not been designed to be recycled, its components cannot be easily separated or it is too toxic. So, more radical solutions are needed to solve the LE problem.

Ideally, before we make things, we need to have thought about what we are going to do when they reach the end of their useful lives. For example, if a product is damaged after being used, how can it be designed from the beginning to be easily repairable? This is the opposite of artificial obsolescence – the pattern adopted (and encouraged) by manufacturers and retailers to increase their future sales. Instead of buying a new product, we could just repair it and this repaired item represents one less product being produced. However, companies seek to expand profits not only through reducing costs, but also by innovating to increase sales. So, what if products were designed to also be easily upgradable? Instead of buying a new one, it would be cheaper to buy an upgrade. Again, the upgraded item represents one less article produced, which decreases expenses, energy consumption, CO_2 emissions and resources extraction.

That said, we now recognise that whilst computer software is constantly evolving the ability of computer hardware to keep up struggles – whilst many computer companies have tried in the past to make system hardware upgradeable – it ultimately becomes obsolescent. If this is the case, how about designing products that when 'repair' or 'upgrade' are not feasible options, their materials could be easily extracted and reintroduced into the market for raw materials? In other words, items are designed to be 'better waste'. An economy that allows resources and energy to return to the consumption process by building products to be re-used, repaired, recycled or refurbished is a more sustainable and resilient one. As anticipated from the beginning of the book, CE is an alternative approach to the current linear consumption system. Figure 3 illustrates this approach and further explanation is provided below.

CE is built upon the following principles and assumptions:

- **Waste is food:** in other words, this is a 'zero waste' principle; waste is meant to be eliminated. All the organic matter (biological nutrients) is returned to a productive use and technical components must be designed for disassembly and repurposing.

- **Diversity is strength:** the resilience of systems to external impacts increases when their interdependencies and links are varied and their network is extensive.
- **Energy must come from renewable sources:** ultimately, all systems should embrace renewable and clean sources to generate all their energy.
- **Prices must tell the truth:** the prices of commodities and services need to be real and accurate; they must include environmental and social costs.
- **Systems thinking:** it is fundamentally important to understand how things impact and influence one another within a whole.

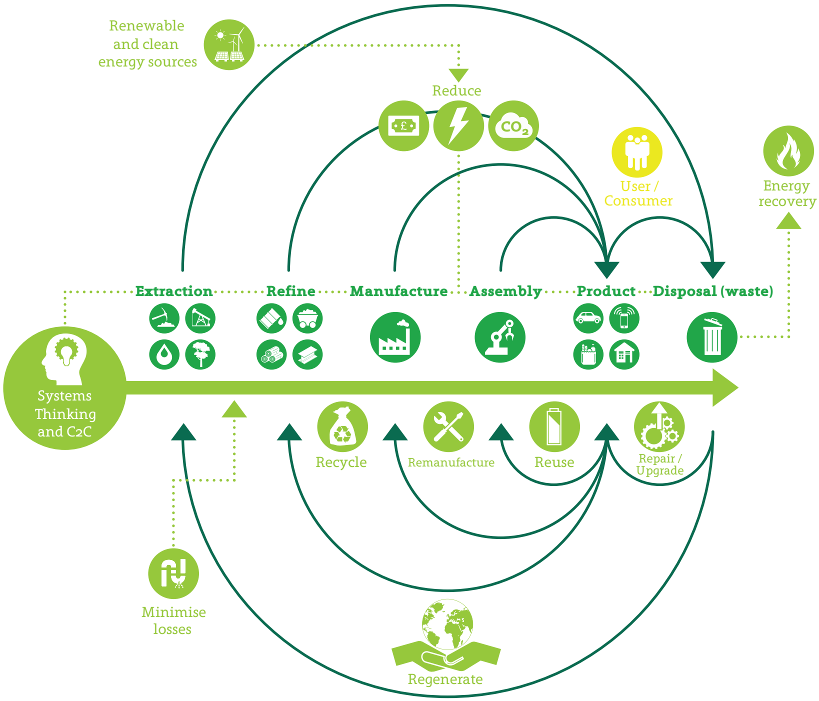

Figure 3. The Circular Economy

Why should the Circular Economy be implemented?

There exist many reasons to implement CE in cities, for example:

1. our planet's environment is deteriorating dramatically, due to poor regulation and to rapid industrialisation and urbanisation;
2. shortages are already being experienced due to the increasing demand for resources and energy;
3. new, more efficient methods of production will be required in response to stricter standards in terms of labour, environment and production, and increased regulation of international trade;
4. important changes in education, technology and regulation could be achieved if CE was implemented as a development strategy; and,
5. it will contribute to material security, savings in resource use and development of alternative energy sources.

It has been estimated that CE could bring about many economic and social benefits. For example, the Ellen MacArthur Foundation, Fund for Environmental Economics and Sustainability (SUN; acronym in German) and the McKinsey Center for Business and Environment (2015) calculated that its implementation in the European Union could realise net material cost savings of as much as $630 billion annually in medium lifespan products (electronic devices, motor vehicles, machinery, computers) and up to $700 billion per year for commodities (apparel, beauty and hygiene, food); this equates to a 6.7% growth in GDP. In Sweden, for example, it would mean a potential increase in jobs creation of 3%. In terms of environmental benefits, it has been estimated that CE could contribute to reduce waste generation by 35-40% and decrease GHG emissions by 70% by 2050, compared to 2012 levels in the EU.

Strategies in support of CE are presented in the following five sub-sections.

Thinking in terms of systems

A system is the constant interaction of a group of elements that have the purpose to achieve a common goal, thus making the whole greater than the sum of its parts. To comprehend all the relationships and interdependencies of things and to consider the potential impacts of these interactions, it is necessary to draw on systems engineering and systems thinking. In terms of waste, for example, the integration of waste management infrastructure into an urban system-of-systems allows us to approach Sustainable Solid Waste Management (SSWM).

Systems thinking describes different ways in which systems work and how changes may have an impact over time. Some of the actions performed when thinking in terms of systems are:[21]

1. Understanding the big picture: examine the system as a whole rather than the details of its parts.
2. Observing changes of elements over time, recognising that the behaviour of a system is determined by its structure.
3. Identifying the nature of complex relationships, make meaningful connections and viewing systems from a number of different perspectives.
4. Exposing and challenge assumptions, understand problems fully and identify where actions may lead to significant impacts.
5. Considering the consequences in the short and long-term, and noticing the rates of change.
6. Accounting for new information as it emerges, such as time delays, data from monitoring and evaluation of a system, to take action in order to maintain the system's functions and ensure it produces the desired results.

The SSWM system, for example, raises many concerns and needs to be addressed by all the technical, financial, economic, social, legislative and environmental approaches that support its function. This can be done with a series of maps, which provide a good underlying frame of reference about the context. In so doing, systems, and indeed the world, would become more meaningful if we could provide maps of how everything functions. However, with complex systems, such as cities, such an approach is not easy. Once achieved, though, the level of understanding and challenging, of current ideas, would increase exponentially.

[21] To learn more about systems thinking and its importance, refer to the website: http://waterfoundation.org/.

Hierarchy of waste management

Amongst the different strategies used to manage waste, a hierarchy exists. In other words, some are considered to be more desirable than others, as shown in Figure 4. The actions on the top of the pyramid are the most desired ones: they are the first options to consider when dealing with the rubbish we produce from all our activities. Conversely, the strategies located at the bottom of the figure represent the least desirable, like sending our waste to landfill. The further down the pyramid we go, the smaller the contribution it makes to CE.

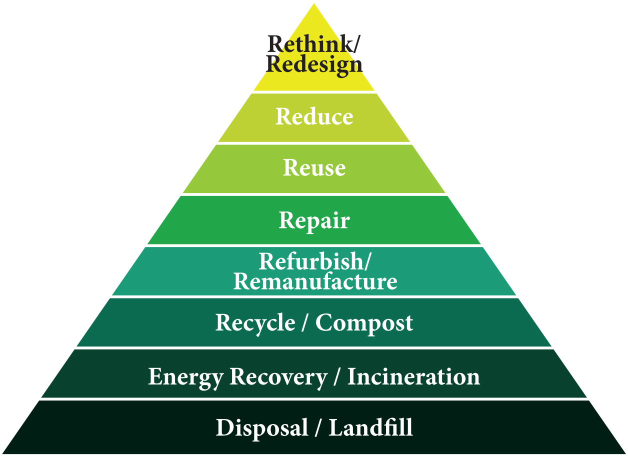

Figure 4. The Waste Management Pyramid

The hierarchy was first known as the 3Rs of reduce, reuse and recycle. Over time, more waste treatment options were added as it was developed. All of them are ranked in terms of achieving the goal of minimising waste generation.

The top priority is to prevent the generation of waste rather than deal with it. It involves changing the thinking when designing and producing goods to make them easier to manage after use; this is often referred to as pre-cycling.

Even though it was developed for solid waste, this set of strategies can also be applied to many other areas. For example, to reduce could mean to minimise consumption or the use of energy/water/fuels. However, in any sector this involves educating people to purchase and use only as is necessary – the adage of 'needs' vs 'wants'. To re-use (or re-purpose) means giving the waste items a new purpose without having to go through a major process, for example using a jam jar to store granola. To repair means to restore something to a good condition to keep it working and maintain the same function. Repairing involves minor fixes in comparison to refurbishing/remanufacturing, which focuses on transforming the article to enhance it or change its appearance or even to mend defects or failures. Refurbishing/remanufacturing therefore means to rebuild a product to the original specifications by reusing existing parts and/or recycling worn out parts in combination with new components.

Recycling is the most well-known of the waste management strategies. It is any activity that involves recovering materials to reprocess into new products, either for their original or a new purpose. We are all familiar with recycling paper, cardboard, glass and certain types of plastic. Recycling organic material by composting it is another prime example. There are two main methods to degrade organic matter: aerobic and anaerobic digestion. In the former, oxygen is needed and it yields compost, which is rich in nutrients for plants and can be used as a fertiliser with further treatment. The latter is performed by bacteria without oxygen. The process yields compost and methane, the main component of natural gas which can be used as a fuel. The methane must be captured properly, otherwise it is released into the atmosphere and contributes to the greenhouse effect – hence, global warming.

Incineration means to burn waste. Energy can be recovered from this process, in which case, it is called Energy from Waste (EfW). The efficiency of EfW can be enhanced by combining energy and heating generation in Combined Heat and Power (CHP) plants. However, it can be argued that generating waste and burning all the materials and nutrients in it, rather than recovering them, is more of a linear approach. Moreover, emissions from this process should be controlled, as many dangerous materials are burned and toxic gases could be released into the atmosphere.

Finally, landfill or disposal should be the last option to consider when dealing with waste. CE aims for a zero-waste generation philosophy. So, in fact, disposal is dismissed as an option for the final outcome for resources. Landfill means filling holes in the ground with waste. In addition to exhausting city-land space, an important issue that arises is the generation of leachate – which is when rainwater enters the landfill and as it passes through, it leaches out chemicals; effectively this involves carrying some of the waste's components out into the surrounding environment. These chemicals may cause soil and groundwater to become polluted with heavy metals. Biogas is generated in landfill as the waste degrades and is another potential problem: it needs to be collected before it escapes into the atmosphere just like in composting. Both consequences start soon after landfilling and may last for centuries, which is why landfill sites are carefully engineered to prevent them causing pollution.

Cradle-to-Cradle

Cradle-to-Cradle (C2C) aims to change the current design of products and services to be safer and friendlier to the environment and human health. All resources used in human activity can be considered as 'nutrients' and are categorised into:

1. biological, which should be designed to be recovered by natural cycles, and;
2. technical, which need to be designed to be reused perpetually by the technical and industrial cycles of humankind.

Innovation and design play an important role in improving products to transform them, post-use, into 'better rubbish'. The product's design should be based on:

- conservation of function,
- delay of quality loss,
- avoidance of toxic materials,
- facilitation of the reintroduction of materials into the economy by predicting the future requirement, and
- value materials in waste as inputs in the consumption process.

"True recycling" is stated by Annie Leonard (2008) to involve designing lasting products that are embraced by local communities for their subsequent collection, cleaning and recycling at the end of their useful life. This would boost the local economy, create jobs and most importantly, in terms of CE, decrease demand for raw resources.

Industrial Symbiosis

In the biological sciences, a symbiotic mutual relationship between two living organisms happens when both benefit from their interaction. For example, a flower produces nectar which attracts and feeds a hummingbird; while drinking the sugary fluid, the bird facilitates the pollination and thus the reproduction of the flower. What Industrial Symbiosis (IS) does is take this ideology and apply it to two or more different industries facilitating symbiotic, mutually beneficial interactions between all. Specifically, IS avoids the disposal of waste after production by converting it into something that is valuable to another industry.

If planned carefully, IS can take advantage of multiple interactions between several industries, which ideally should be closely co-located to avoid long-distance material transport. This is achieved by the mutually beneficial sharing and exchange of resources such as water, materials, energy and most importantly waste streams, which are considered a secondary source of resources. This allows industries not only to improve environmental quality, but also create products with added 'sustainability' value, not least economic value due to the decrease in production costs (for the waste/resource recipient) and waste disposal costs (for the waste/resource supplier). IS essentially relies upon taking advantage of synergies in production processes – synergy (in this case) being the interaction between processes such that their combination yields a greater effect than if they worked separately.

An example of such synergy – agricultural symbiosis – is an ancient Mesoamerican agricultural practice called 'Three Sisters', illustrated in Figure 5. Natives used to grow three major crops together: pumpkin, maize and beans, because they would benefit from each other: maize provides a natural firm structure for the beans to climb, beans provide more support to the maize plant making it more resistant to wind and, most importantly, the roots supply nitrogen to the soil, a key nutrient for future crops. Pumpkin leaves grow scattered superficially throughout the land, acting as a natural "mulch"[22] providing shadow, which prevents weed growth and conserves moisture. Furthermore, the crops complement each other in terms of nutritional value: maize provides carbohydrates, beans are rich in proteins and pumpkin has lots of vitamins.

This reiterates, the need for geographic proximity as an important factor to enhance IS, not least for industries. However, it has been argued that this characteristic is not

[22] A superficial layer of organic material applied to agricultural soil with the purpose to minimise weed growth and improve the zone's visual appeal, as well as retain moisture to help crops survive droughts.

the only, or even the most important, factor for IS,[23] and on its own is certainly not always enough. Thus, industrial clusters and industry agglomeration(s) should not

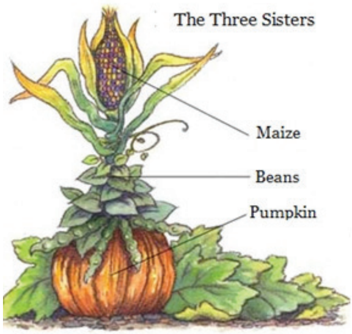

Figure 5. The 'Three Sisters' Agricultural Practice

be mistaken for IS practices. Just to reiterate, IS is primarily associated with the efficiency and effectiveness of resource flows, and if waste from one process can be used as a resource for a second then efficiency (not least economics, primary resource use and waste reduction) increases. The transfer of the resource from one industry to the next then constitutes an important part of the business model, and this itself can be judged in terms of economic and environmental costs, like energy, resource, carbon, etc. When considering IS and its benefits, it should be noted that for resource efficiency, it is important to build sharing networks of information and to promote innovation. IS contributes to the transition towards a CE mainly on a local scale.

Product Service Systems

Product Service Systems (PSSs) change the focus from the products themselves to the actual requirements of the user: the services to be provided. In other words, it requires a shift of thinking towards the result or service delivered, rather than the product sold to the consumers. These systems prioritise the ultimate functionality and satisfaction that the user wishes to obtain. Although PSSs are not sustainable *per se*, they provide much more degrees of freedom to find sustainable solutions. The

[23] Lombardi, D.R. and Laybourn, P. Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries, *Journal of Industrial Ecology*, 2012; 16 (1), 28–37.

main types of PSS are classified as follows:

- **Product-oriented services:** this is still focused on selling the product, but additional services are offered. For example, a maintenance contract, a take-back agreement when the product expires or advice on how to optimise its use.
- **Use-oriented services:** the product is not sold; it remains in the provider's ownership and the provider oversees repair, maintenance and control. The product can be: 1) leased – granting the user unlimited and individual access, like a flat letting; 2) rented – not unlimited nor individual access, other users may use it at different times, like a car rental; or 3) pooled – several users have access at the same time, that is, they share it.
- **Result-oriented services:** no product is involved but a result or service is agreed by the provider and customer. The types are: 1) outsourcing – or paying for another company to perform an activity, such as office cleaning; 2) pay per service unit – printers are the best example of customers buying an output/result; and 3) functional result – companies focus on delivering an agreed result while providers are entirely free on how to do it, e.g., a company that promises retailers to ship merchandise to clients.

Business models based on providing the benefit of a product without owning it, offer savings for the consumers and providers. If more people use the service instead of buying the article, fewer goods, resources and energy are consumed in general. Firms will have more time and resources to focus on delivering the results demanded. Thus, companies are responsible for, and have an incentive to develop better processes of, maintenance, quality improvement, efficiency, recovery and recycling of materials, and energy savings. If products are a cost factor, then companies have an incentive to prolong the products' service life for as long as possible. Not owning artefacts and paying for the result we need lightens the environmental burden while satisfying the real needs of people. This is a growing trend in many spheres, from items such as CDs and books (electronic devices can provide these without the need for physical forms) to tools, garden machinery, apple presses and suchlike that are needed only intermittently and can be hired as required.[24]

[24] To learn more about sharing in cities refer to: Boyko, C.T., Coulton, C., Pollastri, S., Clune, S., Dunn, N. and Cooper, R. The Little Book of Sharing in the City, Lancaster. 2016. Available at: http://imagination.lancs.ac.uk/outcomes/Little_Book_Sharing_City

Different business models

Firms of all ages, sizes, locations and sectors should combine their processes of innovation with a consideration of implementing CE principles in their business models. With an eye to resource efficiency, and environmental benefits more generally, and the potential for brand enhancement, they should design their products and services to optimise the extended use and reuse of all their resources. In this section, we present two examples of CE principles in business models for the mobile phones sector and the brewing industry.

Mobile phones

Smartphones are replaced constantly and it is important to find ways to make this product more sustainable. We need to find how to make it convenient (for both consumers and manufacturers) to reuse phones and their components. According to data from the World Bank (2017),[25] mobile phone subscriptions worldwide increased from 90.7 million in 1995 to 7.2 billion in 2015. In the UK, the numbers are just as surprising: subscriptions have increased from 5.7 million in 1995 to 79.3 million in 2015. Mobile phones are just as common in Nigeria as in the United States. Moreover, in countries like Kuwait, Hong Kong and Macao, the average mobile phone subscriptions per person ranges from 2.3 to 3.2. This gives an idea

[25] World Bank. Mobile cellular subscriptions, International Telecommunication Union, World Telecommunication/ICT Development Report and Database, 2017. Available online: https://tinyurl.com/yccqsg6b (accessed 9 July 2017).

of how many resources (including rare and critical materials) were used, and CO2 emissions generated, to produce so many mobile phones.

In general, smartphones are difficult to manufacture. Their materials are rare and they require complicated assembling processes. If we imagine a smartphone designed to be easily repaired, users may be more willing to pay for a repair than for a new phone if it is damaged.

Innovation seeks constantly to upgrade technology; new smartphones are launched with better cameras or batteries. However, if a smartphone is designed to be fixable it can also be upgradable. Consumers may prefer buying an upgrade instead of a new device. But what if repair or upgrade is no longer a feasible option? In that case, it should be designed to recover its materials easily so manufacturers could reuse them in building new products, or maybe use the components in a different gadget, like a smart washing machine.

A repaired or upgraded phone represents one less device produced. Thus, companies extract, refine, process, manufacture and assemble less, consuming fewer resources and reducing their expenses. All smartphones would be cheaper if they were easy to fix, upgrade or disassemble. But, how do we make sure that they will go back to the manufacturers once their lifespan has ended? An option would be a PSS.[26] A leasing system, in which we are not buying the phone, but we pay to use it unlimitedly and individually until the manufacturer decides that it is time for it to be returned. This could be because it needs to be replaced for an updated version, the materials are needed for another phone or repair is no longer possible. Mobiles phones are just an example of where this is occurring in practice (but could be far more widespread), but certainly the same thinking is being applied to automobiles, and could be extended to white goods, furniture, computers and so on.

[26] For more details on how refurbished smartphones could be sold and how customers view them, refer to: Mugge, R.; Jockin, B.; Bocken, N. How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives. *Journal of Cleaner Production*. 2017, 147, 284-296.

Brewing industry

One of the ideal places to feed livestock, apart from pasture lands, is near breweries where a by-product of the brewing process serves as nutritious food for the animals. An old example of IS is the synergy between cattle bred for beef and spent grains. Beer is made essentially from barley grains being germinated by soaking them and then drying them to stop the growth. The sugars released from the starch in the wet grains are fermented into alcohol through a reaction boosted by yeast and water. Last, aroma and flavour is added with hops.[28]

Taking the organic waste from a process and reusing it as the input for the next cycle, extracting the remaining value in it, is called the "power of cascaded uses". This means that another economic opportunity arises. The objective is that the last step should return the nutrients into the biosphere. For example, the spent grains from brewing beer are still valuable and can be used to make fertilisers and animal or fish food. However, if used for animal food, it retains a higher value (food rather than fertiliser) and the additional process (animal digestion) renders the final product (animal excrement) useful for the creation of fertiliser. Moreover, brewing can also be achieved with bread from excessive or unused production. Instead of going to waste, this short shelf-life product presents the opportunity to extract value from what would otherwise be a waste and allows brewing to take place without any major special technology or process.

Cradle-to-cradle is also important for the brewing industry. Some beer companies have designed glass bottles to be more resistant by adding more material to them. They can be used lots of times (up to 30) instead of just a single-use. This translates into savings from the reduced costs of packaging beer and less glass being used overall. The Florida-based Saltwater Brewery provides another example: it has designed edible six-pack rings, made from the by-products of the brewing process. It was motivated to do this because of the problem of six-pack plastics rings ending up in the ocean, affecting sea life and polluting the ocean – an environmental driver rather than an economic driver – and yet there are multiple benefits that can be

[28] A sector study on CE for beer and other alcoholic beverages can be reviewed on Zero Waste Scotland. Circular Economy Sector Study on Beer, Whisky and Fish, 2015. Available online: https://tinyurl.com/ybbqolzw (accessed 15 July 2017).

gained once such thinking is started.[29]

The brewing industry demands a great amount of water, both for the product and the production stages. To produce one litre of beer requires 4 - 10 litres of water. Using treated, recycled water; harvested rainwater or abstracted groundwater are some of the alternatives to reduce the water footprint of producing beer. Furthermore, some brewing firms are working on maintaining the quality of their water supply sources by keeping them healthy. They seek to improve the surrounding watersheds' conditions, soil structure and groundwater bodies' recovery by planting specific tree species and other vegetation.

[29] Rogers, C.D.F, Application of Foresight in Engineering Future Sustainable, Resilient and Liveable Cities. Civil Engineering, Proceedings of the Institution of Civil Engineers (in press). 2018.

Summary

This little book has introduced the concepts of UM and CE. It has shown the importance of studying the flows of resources in urban areas and presented an example of the use of UM for Birmingham. The book provides a simple and easily understandable introduction to CE, the reasons to implement it and some of the potential benefits to be gained from doing things differently in our current systems - that are heavily based around consumption.

UM has provided the framework for understanding different city resource flows. This, in turn, aids decision-making around waste arising from city flows, the associated pollution as well as the potential (re)use of waste – this informs both CE and IS approaches. As such UM, provides a baseline against which to assess different initiatives (or interventions) and determine their effectiveness over time.

For cities to be sustainable, we need to (re)think and (re)organise how they work. In a city that embraces CE, all the outputs are considered as a potential input for another production system. All types of waste are regarded as a potential asset, rather than a burden, and CE principles are fundamental to how cities function, rather than just an optional supporting characteristic.

Cities worldwide are constantly competing to attract businesses, clients, tourists, investments, immigrants, etc. An additional, potential benefit of implementing CE in cities is achieving far better resource efficiency and resource security. This will result in a competitive advantage by establishing goals for best environmental behaviour and yielding the best performance in both resources and economic terms. There are many different agendas and motives at work in a city. CE provides options to make the best use of the resources we have and reduce waste; in so doing, it addresses many different agendas by offering multiple types of value – economic, environmental, social, cultural, political – and by doing things differently.

In conclusion, we are becoming poor in resources but rich in waste. We are slowly killing our only home, our beautiful planet, by over-exploiting and polluting it. Hopefully this book has helped you to understand the importance of addressing our resource use and waste management problems. We also hope that this book has inspired you to think of new and better ways of doing things when you are designing a business model or a product, looking to be more sustainable in your local community or devising a policy for waste treatment. This book provides the opportunity for consumers, companies, cities and governments to gain greater understanding of their resource use and associated waste, and to work together to develop more sustainable, resilient and liveable cities.

Resources

If after reading this book, you are interested in learning more about UM and CE, we would recommend the following as further reading. Also, this section presents the references cited in the book, and it suggests some of the most important and recognised projects, institutions and initiatives working on the transition towards a CE.

Circular Economy related initiatives

Cranfield University, the world's first degree based on Circular Economy: https://www.cranfield.ac.uk/courses/taught/technology-innovation-and-management-for-a-circular-economy

European Union Commission Circular Economy Strategy: https://ec.europa.eu/growth/industry/sustainability/circular-economy_en

Forum for the Future: https://www.forumforthefuture.org/project/circular-economy/overview

Industrial Synergies: industrial ecology solutions: http://www.international-synergies.com/

McKinsey Center for Business and Environment: http://www.mckinsey.com

The Centre for Sustainable Design: http://cfsd.org.uk/

The Concrete Initiative: http://www.theconcreteinitiative.eu/component/tags/tag/52-circular-economy

The Ellen MacArthur Foundation: https://www.ellenmacarthurfoundation.org/

University College London Circular Cities Hub: https://circularcities.wordpress.com/

Waste and Resources Action Programme (WRAP): http://www.wrap.org.uk/

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