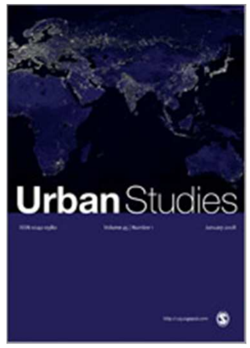

Circular Cities

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Circular Cities

Abstract

A circular approach to the way in which we manage the resources consumed and produced in cities - materials, energy, water and land – will significantly reduce the consumption of finite resources globally. It will also help to address urban problems including resource security, waste disposal, greenhouse gas emissions, pollution, heating, drought and flooding. Taking a circular approach can also tackle many other socio-economic problems afflicting cities for example providing access to affordable accommodation, expanding and diversifying the economic base, building more engaged and collaborative communities in cities. Thus it has great potential to improve our urban living environments.

To date the industrial ecologists and economists have tended to dominate the circularity debate focussing on closed-loop industrial systems and circular economy (circular businesses and systems of provision). In this paper we have investigate why the current state-of-the-art conceptualisation for circular economy (RESOLVE) is inadequate when applied to a city. Through this critique and a broader review of the literature we identify the principles and components which are lacking from the CE conceptualisation when applied to a city. We then use this to develop our own definition and conceptualisation of a circular approach to urban resource management.

Keywords

Environment, Sustainability, Infrastructure, Land Use, Planning, Policy, Circular Economy

1. Circular cities and why we need them

Currently cities consume 60-80% of natural resources globally. They produce 50% of global waste and 75% of green-house gas emissions (Camaren and Swilling, 2012). There is an imperative for cities to transition to increasingly circular economies to reduce the absolute magnitudes of global waste streams and emissions (Liang and Zhang 2011). The UN estimates that 66% of the world's population will live in cities by 2050 (United Nations 2014) while the global urban footprint will triple over the years to 2030 (Seto, Güneralp, and Hutyra, 2012). There are three key drivers for this: increasing size of urban population; increasing affluence; and greater distances over which goods (and food) consumed and waste produced in cities travels.

Large cities will account for 81% of total consumption and 91% of consumption growth between 2015 and 2030, (McKinsey, 2016). This continuous need for materials and energy services has resulted in substantial accumulations of natural resources in buildings, infrastructure, products and waste deposits. At a time when resources are becoming increasingly scarce, these technospheric resource reservoirs might offer an opportunity for more sustainable development, or at least provide an alternative to virgin production and recycling of annual waste flows (Krook et al., 2012).

Currently much of the municipal waste produced in European cities still appears to be landfilled or exported to Asia (predominantly China and India) to be recycled (European Union, 2014). This has created waste dumps in Asia with serious environmental and health implications. However, the introduction of more stringent regulations in some Asian countries (e.g. "operation green fence" in China, 2013) has improved practices; unfortunately, it has also resulted in low grade municipal waste being exported elsewhere (e.g. Vietnam, Malaysia). More challenging markets for some resources (especially paper) has also reduced Chinese interest in recycling, which creates a disposal problem for European cities. Meanwhile companies in Europe looking to recycle materials (for example plastics) are starved of a supply (Laville and Taylor, 2017).

Urban resource security issues are increasingly a problem, particularly for water, food and energy. Currently, half of the world's cities with more than 100,000 inhabitants are situated in areas experiencing water scarcity (Richter et al, 2013) and the number of water-stressed cities is growing rapidly. Asian and African cities are experiencing food security issues (Brinkley, Birch and Keating, 2013). The loss of agriculturally productive land surrounding cities is another key concern. Rising land values caused by urban expansion has put pressure on farmers to either sell or convert to high-value activities. This reduces the hinterland's capacity to support urban demand for food. Meanwhile, cities have become increasingly reliant on global food producers, dramatically enlarging cities resource hinterlands, and exacerbating food security issues. Cities consume 60% of global energy and are largely reliant on fossil fuels, which makes them particularly vulnerable to hikes in fuel price and energy embargoes (IEA, 2008). Climate change exacerbates problems with urban water, food and energy and the likelihood of more frequent natural disasters which threaten resource security.

In shrinking cities (e.g. Detroit, Leipzig) properties and land lie vacant. Between 2000 and 2016 there were 55 cities with declining populations usually as a result of global economic or national demographic trends (United Nations, 2016). Population decline will occur in 17% of large cities in developed regions and 8% of cities globally from 2015 to 2025 (Woetzel, et al 2016). Housing vacancies result in the under-utilisation of infrastructure in cities, including water, sewage, transport, education, health systems leading to wastage of resources (Rink, Haase, et al., 2012). Thus, scale appropriate systems will be needed to support smaller populations. However, vacant land can provide opportunities for temporary uses and urban transformation as long as it accessible (Nemeth and Langhorst, 2014).

Conversely in Hedge cities (e.g. London, Melbourne, Tokyo) foreign and corporate acquisition of land accelerated dramatically after the 2008 economic crisis. The scale of acquisitions has transformed the pattern of land ownership in these cities (Sassen, 2015). To release maximum land value investors have applied to build high value activities on the land (luxury residential or commercial space). Thus, land has been lost for lower value activities, for example industrial activities and green space (Ferm, and Jones, 2016). These activities are essential for the local production of resources, recycling of waste and regeneration of the urban ecosystem (Bolund and Hunhammar, 1999; Gomez-Baggethun and Barton, 2013).

Speculation in hedge cities has also resulted in vacant properties and sites (Sassen, 2015; Cashmore, 2015; United Nations 2017). Global capital has been invested in land and housing as a commodity; as security for financial instruments that are traded on global markets; and a means of accumulating wealth. This financialisation of land and housing disconnects them from their social and environmental functions. Scarcity increases the value of land and properties. Thus vacancies remain in markets where there would otherwise be oversupply

(Cashmore, 2015). Vacancies in properties prevents re-use and results in the under-utilisation of the resource.

Increasing land values has also led to urban densification, resulting in the loss of valuable green and blue infrastructure providing ecosystem services[1] (Gomez-Baggethun and Barton, 2013; Bolund and Hunhammar, 1999). Ecosystem services are integral for the long-term sustenance and renewal of the urban ecosystem, environmental regulation, as well as the health of the population (Demuzere et al, 2014; Gomez-Baggethun and Barton, 2013). The loss of these services is becoming increasingly important in stressed urban environments suffering from flooding, heating, pollution, declining biodiversity and soil degradation.

A circular approach to the way in which we manage the resources consumed and produced in cities could help to address the consumption of finite resources globally. It could also help to tackle waste production, greenhouse gas emissions, resource security, under-utilisation of resources and the degradation of urban ecosystem services. To date the industrial ecologists and economists have tended to dominate the debate focussing on closed-loop industrial systems and circular economy. In this paper we argue that these conceptualisations are inadequate when applied to a city. We then present an alternate conceptualisation of a circular approach to urban resource management.

2. Current conceptualisation of circular economy

The closed-loop (circular) economy first emerged in the work of Boulding (1966), and was later developed by Stahel and Reday-Mulvey (1976). It was this conceptualisation which became influential upon German and Japanese economic policy during the 1980s and 1990s (Moriguchi 2007; Bilitewski 2007) and encouraged the adoption of circular principles in business and industry. The ideas were further developed in the 1990's by industrial ecologists (Chertow, 2007) resulting in the emergence of the concepts of industrial symbiosis and service-based economies. Neither conceptualisation focussed on the city.

[1] Eco-system services support nutrient cycling, soil production and flood control. They can produce resources (e.g. energy and food) and regulate urban systems (e.g. carbon sequestration, climate regulation, air and water purification).

More recently, circular economy (CE) has gained considerable traction in the world of industry and commerce. CE is a model for production and consumption (with heavy emphasis on production), whose ultimate goal is to achieve the decoupling of economic growth from natural resource depletion and environmental degradation (Jackson, 2009). It places emphasis on the redesign of processes and cycling of materials within commerce and industry. It aims to 'design out' waste, return nutrients, and recycle durables, using renewable energy to power the economy (UNEP 2006). Thus CE is not merely seen as a preventative approach, but as an ecologically restorative and regenerative approach, repairing previous damage by designing better systems within industry (EMF, Mckinsey and Sun, 2015; UNEP, 2006).

The Ellen MacArthur Foundation (EMF) developed the RESOLVE framework for circular economy. The framework defines the principles, identifies key components (or actions) and conceptualises how these operate together to achieve a CE (Figure 1). The EMF defines CE as one that provides multiple value-creation mechanisms which are decoupled from the consumption of finite resources. This definition is based on 3 principles: the preservation and enhancement of natural capital by controlling finite stocks and balancing renewable resource flows; the optimisation of resource yields by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles; and fostering system effectiveness by revealing and designing out negative externalities related to resource use.

[Insert Figure 1 here]

The RESOLVE framework describes 6 actions which will move us towards a circular economy:

1. Regenerate - shift to renewable energy and materials; regenerate the health of ecosystems and return recovered biological resources to the biosphere.
2. Share - keep product loop speed low and maximise utilisation of products, by sharing them among different users.
3. Optimise - increase performance/efficiency of a product; remove waste in production and supply chain; leverage big data.
4. Loop - keep components and materials in closed loops (reuse, recycle, recover, remanufacture) and prioritise inner loops.

5. Virtualise - dematerialise resource use by delivering utility virtually.
6. Exchange - replace products/services for lower resource consuming options.

RESOLVE is the most widely used CE framework for businesses, partly as a result of its promotion through the CE100 network and inclusion in a CE vision for a competitive Europe (EMF, Mckinsey and Sun, 2015). An analysis of existing circular business model types (26 in total) demonstrated that the RESOLVE framework provided the most comprehensive for moving towards a CE (Lewandowski, 2015). Thus, RESOLVE might provide a useful framework to underpin the conceptualisation of a circular approach to the management of resources in cities. However, the RESOLVE framework does have some shortcomings when applied to cities. This is unsurprising since it was not designed for this purpose. Nevertheless, there does appear to be a tendency amongst those aspiring to become Circular Cities to adopt the RESOLVE framework and focus on businesses (industrial and commercial) rather than more strategic urban resource management solutions (Williams, 2017).

3. What are the limitations?

So what are the limitations of the RESOLVE framework when applied to cities? Here we focus on six potential limitations which undermine the use of RESOLVE as a framework for circular urban resource management.

3.1 A complex urban ecosystem

RESOLVE is designed to produce circular practices in businesses or industrial sectors. It focuses on the ecological optimisation of the economic system rather than an urban system. Cities are complex urban systems. A wide diversity of actors, operating across different sectors at a variety of scales, all with different motivations, consume and produce resources within a city (Lenhart et al 2015). This is quite a different proposition to dealing with industrial or commercial actors operating within a single sector (as with RESOLVE).

The urban ecological perspective on the ecological optimisation of an urban system, offers a more useful framing for the circular city conceptualisation. Urban ecologists describe a city as a heterotrophic artificial ecosystem (Odum, 1983). The urban ecosystem, contains individual and nested systems from 3 inter-connected spheres: the natural, built and socio-economic environment (McDonnell, et al 2009). The economy is one (important, but not dominant) element in this complex system.

Urban ecologists describe cities as complex organisms which metabolize resources (Woolman, 1965, Kennedy, Cuddihy, and Engel-Yan, 2007). They are composed of a complex network of inter-dependent actors (producers and consumers) between whom resources flow. Resource cycling (looping) both at local and global scales is seen as essential for reducing waste as well as the health of the urban and wider ecosystem (Orr, 1992).

Urban ecologists assert the need for self-sufficiency (staying within local and regional carrying capacity; regulating patterns of consumption and restoring resources) in order to reconnect those living in cities with the consequences of their decisions (Rosales, 2016; Tjallingi, 1995). This requires a more integrative approach to cities and their regions (Mumford, 1968). Both suggest the need to localise resource flows. The carrying capacity of the urban ecosystem and its ability to be self-sufficient, is affected by the health of a city's ecosystem services (Rosales, 2016). Thus, it is important to protect and enhance urban ecosystem services.

Cities are dynamic and adaptive urban ecosystems, evolving with a changing context (Geddes, 1915; Gunderson, 2000). Like all ecosystems cities have the capacity to cope with changes in context, disturbance and stress, returning to a stable state (Bettini, 1998). Thus it follows that the dynamic nature of a city and its capacity for adaptation and renewal is encapsulated in the circular city approach.

Thus, cities should be viewed as complex, dynamic ecosystems through which resources flow between a myriad of actors, across multiple scales and sectors. The health of the ecosystem is dependent on looping "waste" resources, protecting ecosystem services and localising resource flows where possible. This helps to increase the carrying capacity of the urban ecosystem.

3.2 Consumption

RESOLVE focuses on production, rather than consumption, yet cities are centres of both. Changing the practices and consumption habits of those living in cities, will be critical to the delivery of resource decoupling (Zaaman and Lehman, 2011). More specifically if citizens do not "buy into" consuming circular products and services (e.g. recycled goods, renewable energy) or adopt circular practices (e.g. repairing or upcycling goods, composting organic waste), then a circular society is undeliverable. Thus, an equal emphasis should be placed on delivering circular practices and production systems when considering how to manage resources in circular cities.

Drawing upon the sustainable consumption literature, it seems changes in social practice are dependent on a combination of lifestyle choices and systems of provision (Figure 2). RESOLVE focuses on small-scale systems of provision (or production), usually within organisations or a single industrial sector. It does not consider complex urban systems of provision, across multiple sectors. Nor does it consider how these systems of provision interact with the varied lifestyles of those living in cities, producing different social practices. Furthermore, RESOLVE does not focus on lifestyles, and how lifestyles themselves can influence citizens' willingness to adopt circular practices (e.g. the "time-poor" are less likely to up-cycle household goods).

[Insert Figure 2 here]

As the demography of cities change the lifestyles and social practices of those living within them will also transform. Changes within the economy, may influence working habits (e.g. home-working), impacting on lifestyles and social practices, as well as systems of provision. Both have consumption and resource implications. For a "circular" society to emerge, consumption patterns produced by lifestyles, social practices and systems of provision will need to be tackled. Thus, we must consider consumption patterns in our conceptualisation of a circular city.

3.3 Land

RESOLVE ignores land, yet land is often the most valuable resource in cities. For example, the average price for land with planning permission for housing is around £6,000,000 per hectare in the UK and rises to £100,000,000 per hectare in the City of London (DCLG, 2015). Thus, land which remains vacant because of the cost of decontamination, difficulties with land assembly or simply due to speculation, is a waste of a valuable resource. Land recycling should be facilitated in a city to optimise resource use.

In hedge cities land speculation drives economic growth, but it also prevents low value activities. Often circular actions (e.g. regenerative urban forestry; recycling industries; pop-up activities on derelict land) could be considered to be low value activities. All these activities require space within cities. But they compete for space unsuccessfully with high value activities and thus often remain absent. Conversely in shrinking cities the opposite appears to be true. The value of land reduces and new development trajectories are sought. Thus opportunities emerge for low-value activities including circular actions, for example urban farming and forestry in Detroit and Leipzig.

Land offers ecosystem services which are essential for regenerative processes in cities (Costanza et al, 1997). Cities are dependent on large hinterlands for resource provision and assimilation of waste. In a study of the 29 largest cities in the Baltic Sea region, it was estimated that the cities claimed ecosystem support areas at least 500–1000 times larger than the area of the cities themselves (Folke et al., 1997). Allocation of land in cities for ecosystem services for production (e.g. urban agriculture); to tackle the degradation of natural capital (e.g. carbon-dioxide emissions using urban forestry) and environmental hazards (e.g. alleviate flooding using sustainable urban drainage systems) could potentially help to reduce the resource hinterland and regenerate the urban ecosystem.

Land-use patterns and urban form can affect resource consumption, particularly energy used in transport and buildings. For example, mixed-use development localises trips (Stead 2001) and can enable industrial symbiosis (Pandis, 2014). Conversely, zoning can create significant barriers to both. Land allocation for lower value activities – for example industrial purposes or ecosystem services - is essential for the successful implementation of circular actions in cities.

Thus, land is incorporated into our conceptualisation of a circular approach to resource management. Firstly, it is a valuable resource (equally as valuable as water, materials and energy). Secondly it provides space for circular activities, which affect the city’s ability to assimilate “waste”. Thirdly, it offers ecosystem services which are crucial for the regeneration of the urban ecosystem. Fourthly, land use patterns affect urban activities and thus resource consumption. Finally, land use also affects the feasibility of adopting circular actions (e.g. localisation of activities or looping of resources) within a city.

3.4 Infrastructure

RESOLVE also ignores infrastructure in its conceptualisation. Yet infrastructure governs how resources are supplied, managed and consumed in cities (Chester and Allenby, 2017). Infrastructure facilitates the strategic circulation of resources – materials, water, energy, goods - in cities. Integrated infrastructural systems (e.g. the Hammarby model) can enable the circular flow of resources, across sectors, within urban systems, thus helping to reduce the resource intensiveness of cities and tackle the urban waste stream (Jonsson 2000).

However, the segregation of infrastructural systems reinforced by institutions, regulatory frameworks, funding mechanisms, technological capacity and physical urban form can prevent the adoption of integrated, circular resource systems (Williams, 2013). This in turn locks-in consumption behaviours which reinforce the linear, waste-producing systems. The socio-technical lock-in prevents changes in the way in which resources are supplied and consumed within cities.

Urban infrastructure is also a resource mine. The construction and maintenance of infrastructure accounts for more than 50% of the total global raw resources consumed yearly, and for more than 33% of the total global energy use and associated emissions (Giesekam et al., 2014; Ness et al., 2015; Purnell, 2013). Thus the reuse or recycling of infrastructure must be prioritised in a circular city (Lacovidou and Purnell, 2016).

Infrastructure will be included in our conceptualisation of a circular approach to resource management in cities. Infrastructure embodies resources (materials, components and structures) which can be re-circulated in the urban system; manages the strategic flow of resources; influences supply and consumption patterns. Thus it can be designed to encourage circular resource flows.

3.5 Adaptation

The need for adaptive infrastructure to facilitate circular economy appears to be overlooked by RESOLVE. Adaptive capacity is particularly important in the urban ecosystem (Geddes, 1915; Gunderson, 2000; Bettini, 1998). There appears to be limited capacity to adapt the infrastructural systems that have been deployed in cities (Chester and Allenby, 2017). In the developed world, the core physical structures that define our infrastructure have often not changed for long periods. These systems may have been upgraded using new technologies, but the core structures have been used for decades. Some infrastructure is old and in need of rehabilitation or replacement. Some is new and likely to last into the long-term making change difficult whilst some infrastructure is yet to be built. The latter could provide an opportunity for affecting design and encouraging adaptiveness. However, socio-technical lock-in often prevents adaptation (Chester and Allenby, 2017). This becomes a problem when societal demands change and new systems of provision are needed. These changes can render infrastructure obsolete or at best mean it is under-utilised. This wastes resources in cities. Yet the demolition and renewal of infrastructure also has resource implications.

To limit waste within the built environment, we need to plan for change, create some flexibility to enable the adaptation of infra-systems. The competencies and system properties that can help enable adaptive capacities require novel planning techniques, technical and institutional structures, and integration of education and interdisciplinary practices across the life-cycle of infrastructure (Chester and Allenby, 2017). Infrastructure which is modular, compatible and flexible alongside institutions which are equally flexible help to deliver adaptive infrastructure. For example, by incorporating spare capacity into urban infrastructure systems (using vacant land, flexible buildings); or opting for smaller, modular systems (e.g. community-scale energy systems) which can grow organically, urban infrastructure can begin to co-evolve with societal change. Thus, planning for infrastructural adaptiveness will be added to the actions central to a circular approach to resource management.

3.6 Scale and localisation

Urban ecologists suggest the importance of self-sufficiency for ecological optimisation in cities (Rosales, 2016). However, the scale at which resources circulate (within districts, city-regions, nationally, internationally) is ignored by RESOLVE. In the globalised economy (in which most businesses and industrial sectors operate) circular resource flows tend to happen across international boundaries. Yet localisation of resource flows is critical for decoupling resource consumption from economic growth (Curtis, 2003). Uniting production and consumption within local boundaries significantly reduces the resources consumed by transportation and the emissions produced.

It also ensures that both positive and negative externalities of resource consumption are localised (Rosales, 2016). This increases the pressure to deal with negative impacts and maximise positive impacts locally. These feedback loops can provide powerful motivation for change in social practices, lifestyles and systems of provision; thus encouraging resource sharing, optimisation, looping and the regeneration of local natural capital.

Central to this thesis is the creation of symbiotic local capital (Curtis, 2003). Symbiotic local capital comprises natural, social, financial, human and physical capital, which are interdependent and self-reinforcing at a local level. Local social capital reinforces the preservation and restoration of natural capital (Williams, 2005). It is also central to the functioning of a sustainable local economy and localisation of resource flows (Curtis, 2003). Social capital enhances the benefits of investment in physical infrastructure and human capital (Putnam 1993). It also increases the likelihood of local resource looping and sharing.

Local knowledge creates appropriate solutions for the protection of natural capital. Physical capital (infrastructure) is designed to support the circulation of economic activities and resources within the local economy. Physical proximity can also support resource looping, sharing and optimisation. The emergence of local business, industry and financial institutions is encouraged to increase economic self-reliance, promote local environmental protection and build human capital. This also encourages resource optimisation, sharing and looping. Thus local symbiotic capital will play an important role in the successful implementation of a circular strategy.

Realistically, in a globalised world the extent to which resource flows can be localised is tempered by local resource availability, the global economic system, the local physical environment, political will, social practices, socio-technical lock-in and lifestyles. Hence, resources will continue to circulate at a variety of scales. However, more flows could be localised, partly facilitated by other circular practices. Thus, localisation is included amongst the actions which can be taken to support a circular approach to resource management in cities.

4.0 The circular approach – a conceptualisation

RESOLVE provides a useful basic framework for conceptualising a circular approach to urban resource management. The 3 principles and 6 circular actions provide a useful guide for those developing and implementing resource management strategies for cities. However, it is a framework for an economic system (industrial sector or business) rather than an urban ecosystem. There are over-arching dimensions - consumption, scale and complexity - which require consideration in the circular approach. In addition, land and infrastructure are important resources which should be integrated into the conceptualisation. In terms of actions for encouraging the circular flow of resources RESOLVE covers most options. However, the localisation of resource flows and adaptation (renewal) of infrastructural systems are arguably missing. Finally, the RESOLVE actions "virtualisation" and "exchange" both appear to represent different forms of substitution. Thus, we group them together as substitution actions (Table 1).

The conceptualisation of the circular approach can be broken down into 3 stages (Lewandowski, 2016):

- providing a definition by outlining the principles;
- identifying the components (fundamental constructs and constituent elements) derived from the main principles;
- Finally describing the relationship between the components (the conceptualisation).

[Insert Table 1 here]

4.1 A definition and principles

The circular approach has three principle aims: to reduce resource consumption and waste; preserve natural capital and ecosystem services; and design out negative externalities (economic, social and environmental) associated with resource wastage, degradation of natural capital and ecosystem services in the city (Table 1). This must be achieved within the context of continually changing demands, consumption patterns and systems of provision in cities. Thus the urban ecosystem undergoes a constant process of renewal, whilst minimising the consumption of resources and production of waste.

4.2 Components

The city is viewed as a complex, heterotrophic artificial ecosystem in which resources are produced and consumed by a variety of activities, initiated by inter-dependent actors, across multiple sectors and scales. Materials, water, energy, land and infrastructure are produced and consumed by actors within the urban ecosystem by a range of activities. These activities relate to the consumption, creation and operation of the city (systems of provision and consumption). Activities include: travel, shopping, leisure, education, manufacturing, construction and farming.

Two sets of actions can be taken in a city to deliver the goals outlined in 4.1. These are circular actions and supporting actions. Three circular actions are fundamental to the delivery of the circular processes: looping, regenerating and adapting. Looping reduces resource wastage by closing resource loops through recycling, re-use and energy recovery. In cities this may manifest in many ways, for example as waste-to-energy plants; "remakeries"; grey-water recycling; refurbishment of buildings and land reclamation.

Regeneration refers to the restoration of the urban ecosystem, preservation of natural capital and essential ecosystem services through the incorporation of green and blue infrastructure into the urban fabric. For example, permeable surfaces, reed-beds, retention ponds, green roofs, urban farms and forests, maybe incorporated into the urban environment to encourage regeneration of the urban ecosystem. Adaptation involves the planning and designing of the city to enable the adaptation and renewal of existing infrastructure with minimal resource wastage**.** For example, through the use of flexible buildings, modular systems and meanwhile spaces.

Four further supporting actions - optimisation, sharing, substitution and localisation – can be used to reinforce these circular actions. The consumption of resources (and production of waste) by producers and consumers is optimised through the use of efficient technologies and processes. This can be facilitated by smart data and design (e.g. smart homes and grids). Redundancies (e.g. vacant sites and buildings; under-utilised energy and water infrastructure) within the urban system can also addressed through design (modular design), regulatory and economic tools (e.g. tax on vacant buildings).

Resources can be shared in cities across a range of activities, including living (e.g. co-housing, library of things), working (e.g. co-working spaces) and travel (e.g. public transport and vehicle sharing schemes). To reduce the consumption of finite resources non-renewable resources can be substituted with renewable resources (e.g. renewable energy); resource-based activities substituted with service-based activities (e.g. buying clean water rather than waste-water systems); physical with virtual activities (e.g. teleworking); durable infrastructure substituted with non-durable infrastructure.

The localisation of resource consumption and production also reduces the consumption of energy in the transportation of products (and associated emissions). It localises the impacts of consumption and can help to encourage pro-environmental behaviour amongst consumers. This helps to protect the urban ecosystem, reduces resource consumption and waste.

4.3 Conceptualisation

The conceptualisation outlines how these actions might operate together to deliver a circular approach to resource management in cities (Figure 3). Three actions are fundamental to a circular approach. Looping, regenerating and adapting underpin the resource cycling processes (natural and synthetic) within the city. They enable the renewal of the urban ecosystem and infrastructure with minimal resource consumption and wastage. However, the three circular actions can be further reinforced, through the adoption of the four supporting actions. For example, localisation of resource flows can help to build local symbiotic capital needed to support more pro-environmental behaviours which underpin successful looping and regeneration actions.

The supporting actions can also reduce the finite resources initially consumed by the urban ecosystem. This reduces the waste (and potential pollution) produced by urban activities, which increases the viability of successfully adopting circular actions. For example, by using energy efficient infrastructure and a renewable energy supply we reduce the consumption of finite fossil fuels and greenhouse gas emissions by the urban ecosystem. We also increase the viability of using "waste heat" and energy recovery to deliver the remaining energy requirements for the city, using looping actions.

Thus resources are consumed by the urban ecosystem, by both natural processes and human activities. New resources are also produced by these processes and which provide resources for the city. The productivity of the urban ecosystem will be influenced by the health of ecosystem services, citizens and local economy. The quantity and type of resources consumed by the urban ecosystem are moderated by the supporting actions. They reduce the resources consumed and "waste" produced by natural and human activities. The remaining "waste" may be addressed through circular actions (Figure 3).

The seven actions outlined are complementary and can operate together in different combinations, depending on the urban context. However, the weightings given to each action will very much depend on the problems encountered in cities (i.e. the resources consumed and wasted in the city; the state of the urban ecosystem; the need to adapt existing infrastructure) and the opportunities to tackle them (i.e. whether there is land available for regenerative activities; if there are opportunities to introduce flexible buildings or new energy systems; if there is a culture of cooperation and opportunities for sharing in the city; or if existing industrial clusters are suited to symbiosis). These circumstances will influence which actions are taken by the city. However, the principal goals of a circular city approach will remain the same.

[Insert Figure 3 here]

5.0 Future Research

In this paper we have investigated why the current state-of-the-art conceptualisation for circular economy (RESOLVE) is inadequate when applied to a city. A circular city is about a great deal more than creating a circular economy and circular business models within the urban context. It is about the regeneration and renewal of complex urban ecosystems.

Through this critique and a broader review of the literature we have identified the principles and components which are lacking from the RESOLVE conceptualisation when applied to a city. We have then used this to develop our own definition and conceptualisation of a circular approach to resource management in a city.

Our conceptualisation provides a reasonable understanding of the principles and components central to a circular city approach. It outlines two types of actions (circular and supporting) needed to deliver cities in which resource consumption and waste is reduced; infrastructure adapted and renewed; and ecosystems regenerated. It explains how these actions can operate together successfully.

It provides a starting point for academic discussion, but needs further substantiation. For example, the diagrammatic representation of the conceptualisation (Figure 3) is currently very simplistic. It focuses on actions (the strategy) for delivering a circular approach rather than the dimensions of a circular urban ecosystem. More detail is needed, particularly in terms of key actors involved, types of activities, infra-systems and resource flows.

Ideally this theoretical conceptualisation should be tested in practice to determine whether the principles, components and the relationships described between the constituent elements are accurate. Further investigations to determine how context effects the actions taken in cities are also needed. However, currently primary data is too limited to do this.

Nevertheless, the conceptualisation is useful in that it provides an indication to practitioners about the combination of actions which can be taken. It also reveals how alternative urban strategies adopted by cities, for example those focussed on resource looping (e.g. zero-waste cities), sharing (e.g. sharing cities), optimisation (e.g. smart or low carbon cities) might be used to complement a circular approach to resource management.

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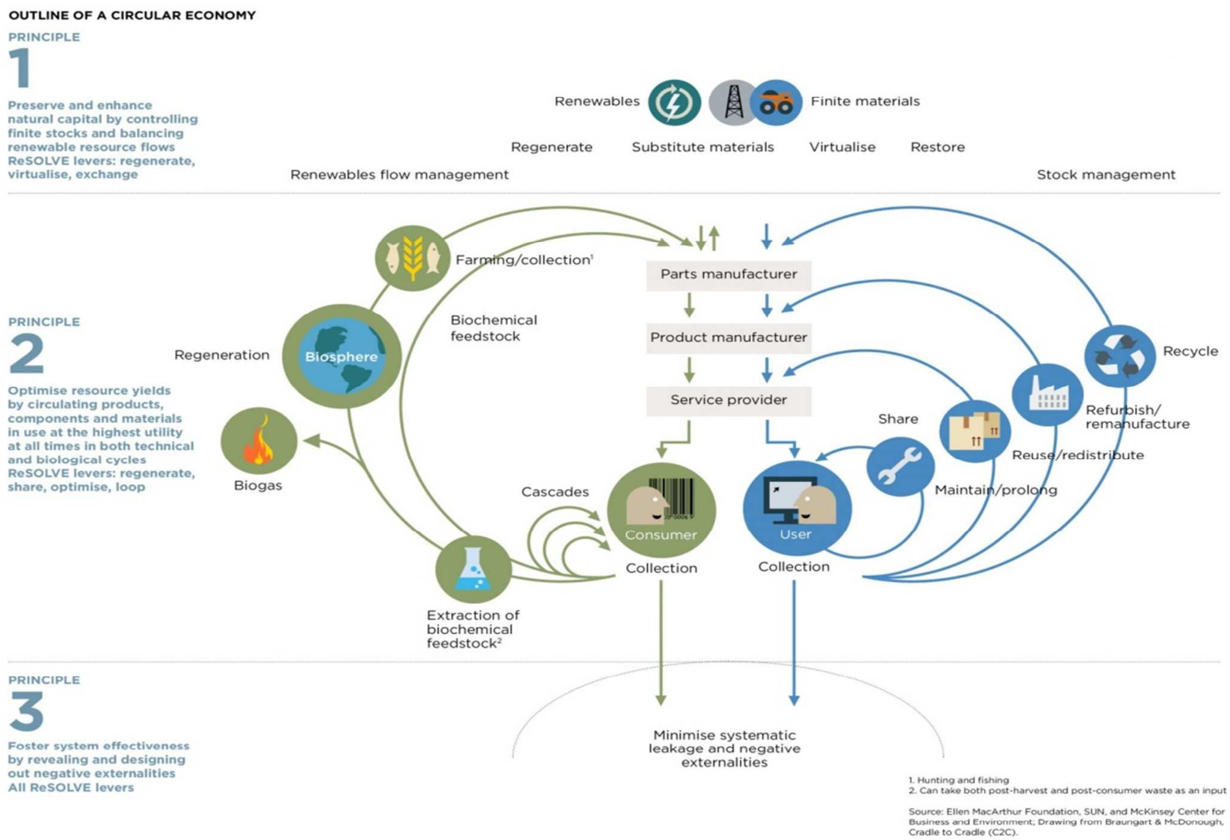
Table 1. Comparing RESOLVE and circular city conceptualisations: principles, scope and actions

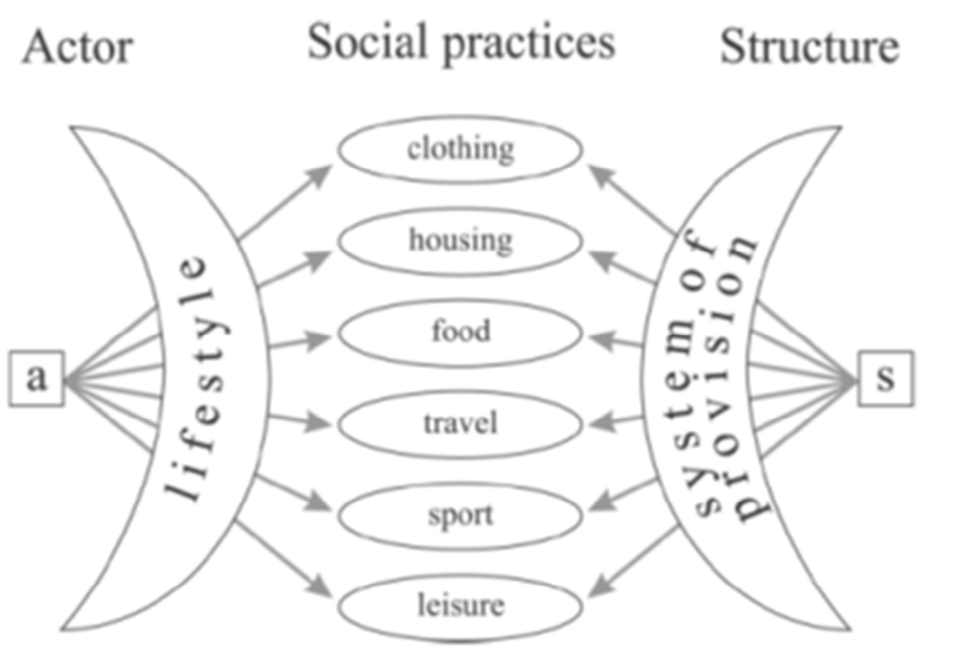
		RESOLVE	CIRCULAR CITY
Principles	Preserve natural capital	The preservation and enhancement of natural capital by controlling finite stocks and balancing renewable resource flows.	The ecosystem supporting the city is constantly regenerated, preserving its natural capital and essential ecosystem services.
	Optimise resource use	The optimisation of resource yields by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles	Resource consumption is reduced (by sharing, optimising, localising and substitution), and all remaining "waste" produced by urban activities is looped. Urban infrastructure is also adapted and renewed for new contexts avoiding wastage.
	Design out negative externalities	Fostering system effectiveness by revealing and designing out negative externalities related to resource use	Designing out negative environmental, economic and social externalities related to resource waste in the city.
Scope	System	Economic	Urban Ecosystem
	Resources	Materials, energy, water	Materials, energy, water, land and infrastructure
	Complexity	Less complex –a single business or industrial sector	Very complex – multiple diverse actors, resources and infra-systems
	Scale	National / international (business or industrial sector)	All scales (with a particular focus on city/local)
	Focus	Focus on systems of production	Focus on lifestyles, social practices and systems of provision
	Sector	Single sector	Multi-sector, cross-sector
	Activities	Manufacturing, supply, transportation and disposal – relating to the production, distribution and disposal of goods / resources.	Travel, shopping, leisure, education, manufacturing, construction, agriculture – relating to the consumption, creation and operation of the city.
Actions	Loop	Keep components and materials in closed loops (reuse, recycle, recover, remanufacture) and prioritise inner loops	Closing resource loops through recycling, recovery and re-using resources.
	Adapt	N/A	Plan and design cities to allow for the adaptation and renewal of urban infrastructure.
	Regenerate	Shift to renewable energy and materials; regenerate the health of ecosystems and return recovered biological resources to the biosphere	Regenerating natural capital and urban ecosystem services.
	Localise	N/A	Localisation of resource flows and activities (consumption and production) within the city-region to develop local symbiotic capital and encourage pro-environmental behaviour.
	Substitution	Virtualise and exchange Dematerialise resource use by delivering utility virtually. Replace products/services for lower resource consuming options	Substitution of non-renewable resources with renewable resources in the supply chain; resource –based activities with service-based activities; and physical with virtual activities, non-durable with durable infrastructure.
	Share	To keep product loop speed low and maximise utilisation of products, by sharing them among different users	Sharing resources in cities across a range of activities (e.g. living, working, travel).
	Optimise	Increase performance/efficiency of a product; remove waste in production and supply chain; leverage big data.	Optimise the consumption of resources by producers and consumers through the use of efficient technologies and addressing resource redundancies with the urban system.

Figure 1. RESOLVE – framework for a circular economy



Source: Ellen MacArthur Foundation, SUN, McKinsey Centre for Business and Environment (2015)

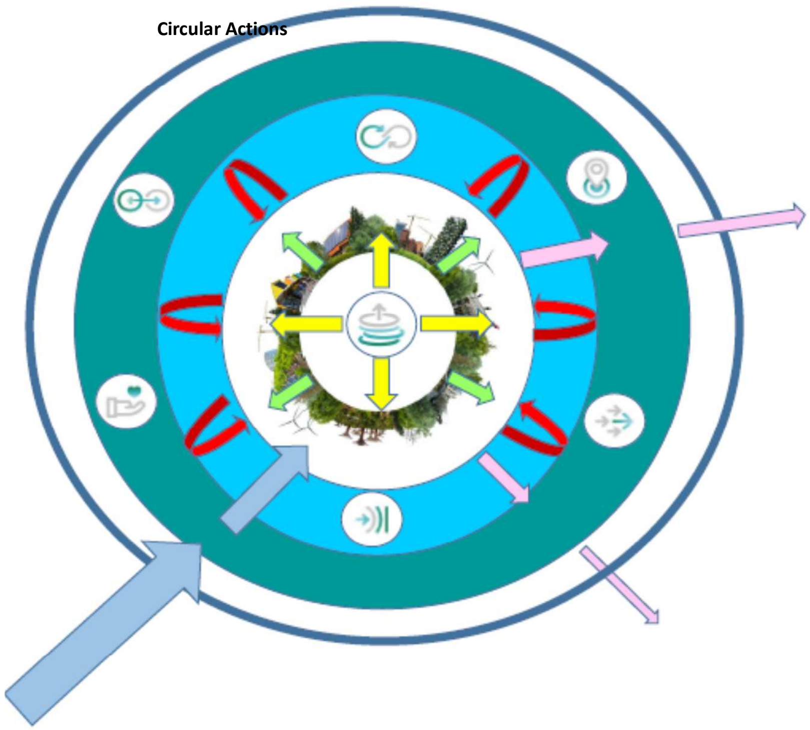
Figure 2. Social practice model



Source Spaargen, 2003

Figure 3. A Circular approach to resource management in cities

Key



Looping actions
Waste-to-energy, "Re-makeries", grey-water recycling, building refurbishment, land reclamation

***Adapt* actions**
Flexible buildings, meanwhile spaces, modular design

Regeneration of the urban ecosystem and ecosystem services and production of resources (energy, food, soil) using *permeable surfaces, reed-beds, retention ponds, green roofs, urban farms and forests*

Support Actions

***Localise* actions**
local agriculture, energy and currency

Substitute actions
renewable energy; service-based provision of heat or clean water, virtual activities (teleworking), durable infrastructure

Share actions
Co-working, cohousing, vehicle sharing, "library of things"

Optimise actions
Smart grid, energy/water efficient buildings

Urban activities
Travel, leisure, education, shopping, construction, manufacturing, agriculture

Resources consumed by urban activities:
land, materials, energy, water and infrastructure

Resources produced by urban activities: products, energy, food,

Resources produced by ecosystem services: clean soil, air, water

Resources wasted

Looped resources