Unmaking Waste in Production and Consumption: Towards the Circular Economy

Book information:

UNMAKING WASTE IN PRODUCTION AND CONSUMPTION

TOWARDS THE CIRCULAR ECONOMY

EDITED BY:

ROBERT CROCKER, CHRISTOPHER SAINT, GUANYI CHEN AND YINDONG TONG

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emerald PUBLISHING

United Kingdom – North America – Japan – India – Malaysia – China

Emerald Publishing Limited
Howard House, Wagon Lane, Bingley BD16 1WA, UK

First edition 2018

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-78714-620-4 (Print)
ISBN: 978-1-78714-619-8 (Online)
ISBN: 978-1-78714-996-0 (Epub)

ISOQAR
REGISTERED
Certificate Number 1985
ISO 14001

ISOQAR certified Management System, awarded to Emerald for adherence to Environmental standard ISO 14001:2004.

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Preface

Unmaking Waste in Production and Consumption: Towards the Circular Economy

Li'an Hou

The annual *Living Planet Report* released by the World Wide Fund for Nature (WWF) and the International Non-Governmental Organisation (INGO) Global Footprint Network revealed that 'Earth Overshoot Day', the day on which humanity starts using more ecological services and resources than the earth can generate, is again ahead of schedule.[1] The 2017 Earth Overshoot Day was August 2, 28 days earlier than 10 years ago, and 67 days earlier than 20 years ago. Facing our current situation of resource shortages and environmental pollution, the linear economic road of 'make-use-waste' has been difficult to maintain, and the circular economy of 'make-use-renew' has become an inevitable choice, to promote the recycling of limited resources, so as to make human society sustainable.

The circular economy requires a fundamental change to the traditional economic model of mass production, increasing consumption and ever larger amounts of waste. From the technical perspective of resource utilisation, the circular economy is to be realised mainly through three means: the efficient utilisation of resources, the recycling of resources through the economy and harmless production. The circular economy is based on resource reuse to achieve sustainable economic growth, which is obviously better than the traditional linear economy, which has relied on the destruction of the natural environment in exchange for short-term economic growth. The development of the circular economy thus not only reduces the waste of resources, but also represents a significant new development model.

In recent years, the economic and environmental costs of traditional ways of developing resources have steadily increased. Some countries have begun to mine deep-sea resources, searching for these deep below the surface of the earth and ocean, and even trying to discover resources in outer space. However, finding these increasingly distant resources, or other alternatives, is not the only way to solve our resource crisis. The circular economy advocates the recycling of raw materials, rather than the continuing pursuit of new resources, as a way of meeting the larger needs of social development.

If the search for new resources involves a kind of 'addition' to economic activity, but one dependent on consuming more resources, then the circular economy involves a 'multiplication' of this activity, but one requiring less resources, and thus less environmental impact. The development of the circular economy is thus the only way to achieve social and economic development before sufficient alternative resources can be found. After years of practice, it has been shown that the production and development model of the circular economy is of great significance to business, environment and society. Facing increasingly tighter resource constraints, 'Unmaking Waste in Production and Consumption: Towards the Circular Economy' becomes an important pathway to implementing the circular economy for the new era.

This book is based on research from both developing and developed countries. Through interdisciplinary exchanges, discussions and studies, it analyses the concept of the circular economy, emphasizing the different contexts in which the circulation of materials through the economy takes place. It presents some unique views on the theory and practice of the circular economy, and embodies some remarkable achievements in the study of its application.

The first half of the book mainly interprets the past and present of the circular economy, at a more theoretical and policy level. This part, starting with the flow of raw materials and the efficiency of resources, explores the internal law and operating mechanism of the circular economy in the light of the consumption of goods and services. The second half focusses on the impact of the circular economy concept on technology and design, from the perspective of enterprise, environment and society and suggests ways in which the circular economy can be applied in new and traditional industries, from the macro level.

The book's authors include dozens of scholars from around the world who have collaborated to develop new insights into the circular economy and its application. In this book, you can find both scientific and reliable firsthand survey data, but also find profound theoretical analysis and research on this developing model for a sustainable future. It can be used as a reference for both researchers and decision-makers, as well as for ordinary readers concerned about how the problems of resource overconsumption and environmental damage might best be solved through the implementation of the circular economy. This book is timely, a valuable contribution to academic and scientific work on this vital topic.

(Translated from Chinese by Dr. Na Ji.)

Note

1. Initially started on December 31 in 1986, Earth Overshoot Day has been moving forward ever since. See: https://www.overshootday.org.

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Introduction

Robert Crocker, Christopher P. Saint, Guanyi Chen and Yindong Tong

> A circular economy is one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times (Webster, 2015)

While there are many definitions of the circular economy currently in use, the one most often cited in English is that from the British charity, the Ellen MacArthur Foundation, given above. Like most others, this starts from the assumption that the earth's 'natural capital', the resources which we depend on, are 'stocks' that need to be conserved, kept in use for as long as possible and reused, rather than being used up as needed and then discarded. This is necessary because the global market at present does not properly account for or price the environmental costs of the extraction of resources, their manufacture into goods, or for the environmental impact these goods have in use or after their eventual disposal.

A number of consequences flow from this commitment to treat resources as both valuable but limited stocks. Firstly, the circular economy includes the idea that all resources, from water and steel to various foods and rare minerals, must be priced and valued according to their costs to the environment, over a full lifetime, through extraction, production, use and discard. Secondly, the circular economy includes the idea that these stocks should be used and reused for as long as possible, whether in their present form or in another – to 'save the earth', but also to retain and, if possible, increase the value embedded in them.

Since how this is to be achieved now depends on a particular resource's market value, the circular economy adds to these fundamental ideas a third one, that the activities dedicated to maximizing a resource's utility, such as reusing a particular material or resource, or extending that product's lifetime in use, can also generate or recover value. By avoiding all losses represented by wasting, and environmental losses incurred through extracting and making something from new and possibly scarce resources, money is also saved. More radically, the circular economy concept adds to this an understanding that this avoidance of waste and return of lost resources into the flow of resources through the economy will of itself stimulate further economic activity, in this way generating employment (Stahel,

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doi:10.1108/978-1-78714-619-820181028

2010). Thus, circular economic activity both avoids losses – in materials, labour, utility and money – that premature wasting necessarily involves, but also generates a range of new economic activities from the processes of recovery and reuse that seemed unworthy of consideration before, in the so-called 'linear economy'.

This last point links us back to the possibility that not only are resources in use now routinely undervalued – in part because their lifetime in use has been artificially shortened and their potentially valuable components and materials wasted – but that innovative ways of using and reusing resources can retain and even increase their market value, and thus greatly benefit the producer as a result (Stahel, 2010). One consequence of this, now widely recognised in China as well as in the EU, is that generating new economic activities through reuse, recycling and remanufacturing, can not only reduce the environmental impacts of industry, but also create new jobs, and indeed, whole new industrial sectors (Stahel & Reday, 1976).

Eager to discover new business opportunities, many large enterprises have become interested in the circular economy concept, at least in part because of the potential added value engaging in circular economic activities promises. In effect, this profitable reuse, broadly defined to include many different kinds of process and material, and many possible industrial actors, recasts the older ideas of environmental sustainability and product stewardship into a form more amenable to calculable economic benefit. For the circular economy concept makes it quite clear that all stocks are inherently valuable, whether this is accurately reflected in their pricing in the 'real' market at a particular moment or not. As the Ellen MacArthur Foundation's website and many reports make clear, it is the hope of discovering some yet-to-be-identified value hidden in their present 'linear' production and its technical processes or supply chains, as well as the desire to improve their environmental performance, that has driven some very large global companies to now embrace and try to implement the circular economy concept (Lacy & Rutqvist, 2015).

As this suggests, the premature wastage of resources represents both a market failure and a loss of value, not only for the companies involved, but also for the societies in which they operate, and that resource flows can be more efficiently and cleverly managed in a systematic way to regain value, whether this is simply reusing, recycling or remanufacturing components and products, or entirely reforming materials into new ones (Stahel, 2010). Not only resources are saved in this shift to the circular economy, but the energy and contributing resources such as water required to make things from scratch are also greatly reduced. Since it is the extraction of resources, and production of new things, their subsequent short-term use and then premature discard, that are now most obviously implicated in the growth of global emissions, the circular economy concept is thus clearly good news for both business and the environment (Lacy & Rutqvist, 2015).

From a slightly different perspective, governments are also becoming more interested in the circular economy, since for policy makers and political leaders resource loss and waste, along with the pollution and environmental damage mining and manufacturing can generate, represent increasingly heavy costs that they, along with the peoples they represent, must absorb and pay for. It is also increasingly apparent to these leaders that while the linear economy, or 'business as usual', might at first create employment and generate wealth, its larger and longer term environmental and social costs can become unsustainable, and ultimately destructive to the same communities they might at first benefit. For example, the global manufacture of plastics now vastly exceeds in volume the capacity of standard methods of disposal or recycling to absorb at their end of life, and so the stock of waste plastics is steadily increasing, along with its long-term, and extremely negative, impacts on the environment (New Plastics Economy, 2017). Most governments realise that this whole industrial move towards the circular economy will require more than some voluntary agreement between the larger manufacturers, but an informed shift in policy, along with appropriate financial and regulatory instruments, to encourage a transformation of each industry.

The added risks now associated with climate change, with rising seas, extreme weather events, environmental degradation and species extinction, have necessarily increased, and made unavoidable, the social and economic costs now associated with the linear economy. Consciousness of these climbing risks, and the increasingly high costs of inaction, are driving the cycle of intergovernmental reports, meetings and commitments that have marked our era. Consequently, governments across Europe and Asia, and especially those within the EU and in China, are in the process of shaping policies, financial instruments and regulations to stimulate and help implement the circular economy. This is in part driven by the urgency of the global environmental crisis, but also by the logic of the circular economy concept itself. Reusing materials and shifting to renewable energy, to conserving resources and reducing wastes, makes more and more sense, and is also more cost effective in the long-term. A number of larger cities and state governments around the world have also begun to embrace the circular economy concept, recognizing the potential benefits of this model for their own environmental, social and economic programs, including increasing employment and 'green growth'. In China, for example, a small city like Jieshou in Anhui province (Jieshou, 2017), is now totally dedicated to benefitting from China's increasing commitment to the circular economy, employing some 40,000 people in circular economic businesses. To take another example, in South Australia, in May 2017, with limited fanfare, the state government announced it would commit itself to creating a circular economy over the next two decades, a commitment that will impact businesses of all sizes operating in the state, and soon lead to a reshaping of enabling legislation and regulation (GISA).

While there is little that is entirely new about the concept of the circular economy, and its origins can be traced back to ideas in currency in the 1960s and 1970s (see Crocker, Chapter 1), its broader implementation is necessarily challenging, requiring a gradual transformation of many economic, technical and material settings, from regulation and taxation through to supply chain management and product design, and this will need to occur in every domain. It will also require a much richer understanding and more detailed knowledge of resources, and of what is now considered 'waste'. What exactly is being wasted, and in what volumes, why this is wasted and how this can be recovered and made use of again, all become important topics for more intensive research and experimentation.

Design, and the application of technology to this end, also become vital components of the implementation of the circular economy. Beyond all rhetorical and marketing flourishes about the economic potential of the circular economy, is the hard work of many researchers re-examining current practices and processes to both transform wastes of all kinds into viable, and safe, resources, for a second, or third, life in use.

This book has been titled *Unmaking Waste* because this phrase accurately sums up what the circular economy must involve, in terms of both future research and industrial practice. While wasting materials, products and components might presently be justified in the linear economy, because through more rapidly wasting what we make and use we make room for the new, and thus can sell more, and keep the wheels of commerce spinning, this is clearly short-sighted and ultimately self-destructive. In contrast, the circular economy allows us to reconceptualise most waste as having some inherent value, and to recognise that waste is typically the final consequence of some decision (whether conscious or not), that can be reconsidered, and in many cases reversed and undone or 'unmade'. Thus, the circular economy is about systematically reducing the speed and extent of the ever expanding and accelerating cycle of extraction, production, use and discard that marks today's present linear economy. This 'unmaking of waste' must be considered not only in terms of the end of the cycle of production, use and discard, as it is presently considered through current practices of recycling (MacBride, 2011), but in terms of design, of reshaping the beginning of this cycle to suit this more circular pattern of material flows, which is the goal of the circular economy itself.

The aim of this book is to bring together examples of recent research exploring some of the consequences of this central idea of 'unmaking waste' to further the implementation of the circular economy in a selection of different contexts. Since the circular economy as a concept requires the radical realignment of many of our cherished ways of designing and making things, using and disposing of them, this book cannot hope to be comprehensive, but rather seeks to cover a broad sweep of exemplary themes with a specific link to the central idea of the circular economy. This is done here through the lenses of many disciplines, including history, economics, consumption, design, material science, marketing, construction and systems innovation. Seeking to stimulate its readers to consider the circular economy's concept and its potential implementation in more depth, it does not seek to 'sell' the concept as a necessary, and marketable, 'solution' to our environmental problems (there are others doing this), but rather to promote more research on the concept and its implementation, as a potential vehicle for the changes required by our growing, and ever more serious environmental crisis.

This book had its origins in the first 'Unmaking Waste' conference held in Adelaide, South Australia, in May, 2015 (UnmakingWaste), with 13 of the essays originally presented as papers to this conference. These essays, now expanded and rewritten, were then augmented over the intervening two years with some additional invited essays, with two originally presented as papers to a related seminar held under the auspices of our China Australia Centre for Sustainable Urban Development (CACSUD) on 'The Futures of Waste' at the University of South Australia in September, 2016. The remaining chapters, mainly focussed on the Chinese experience, were then added to complete the collection of nineteen essays presented here. As editors, we are very grateful to the eminent Academician, China Academy of Engineering, Professor Li'an Hou, for contributing his thoughtful Preface, and to Mr Vaughan Levitzke, Chief Executive of Green Industries SA, whose lifetime of dedication to waste reduction in Australia and our region has been widely recognised, for his kind Afterword to this collection.

The book is divided into four parts, representing four broadly loosely defined themes. The first, *History, Theory and Experience,* is mainly concerned with the larger picture of the history, economics and policy initiatives required to implement the circular economy. It begins with Robert Crocker's essay on the longer history of the 'circular' concept in sixties environmentalism, and how this has shaped environmental agendas ever since, including that embraced in the circular economy. It emphasises the power of design to generate overconsumption and waste, or, potentially, to cure the larger problem this overconsumption has created. This is followed by Martin Shanahan's discussion of the potential role economics could play in further developing and contributing to the circular economy concept, providing an overview of some of the most important of the missing voices. These economists now have an increasing relevance to today's efforts to implement the circular economy. This is followed by Xu Zhao's valuable round-up of the history, development and implementation of the circular economy in China, perhaps the world's first nation to most fully embrace the concept, from the top down, as a means for gradually putting into practice that government's grander goal of creating an 'ecological civilisation', an ideal that the rest of the world could do well to emulate. The final essay, by Norman Goh, Christopher Saint and colleagues, on the potential use and policy implications of the use of biosolids, suggests what the circular economy concept might mean in one presently undervalued resource, water, and the human and industrial wastes it typically gathers as it is makes its way through our linear economy. This last essay begins to reveal to the reader the greater scientific, technical and policy distances still to be covered if the circular economy is ever to be implemented. It also signals or announces the themes taken up especially in the last two parts of the book.

This first part is followed, in the second *Consumption, Design and Behaviour,* by five essays on the implications of the concept of the circular economy on consumption, consumer behaviour and those areas of repair and reuse that are more directly accessible to consumers. In many respects this part picks up on Robert Crocker's initial argument (Chapter 1) that the circular economy needs to be considered also in terms of consumption, and specifically, design for consumption. The first essay in this part, by Hélène Cherrier and colleagues, repositions the consumer's relationship with the consumer product of the linear economy towards one of care and relationship. For as they argue, the object once possessed effectively 'talks back' to its owner, requiring time, place, maintenance and attention: this is a material, psychological and social relationship, and not just a momentary transaction. The consumer's potential custodianship of objects becomes an important topic of research in itself, once one considers consumption and possession as more than just going shopping to stimulate economic growth (see Miller, 2009). This more interactive view of the things we possess and use is followed by an essay on potential ways of approaching the problem of 'fast fashion' by Jen Ballie and Mel Woods. This explores a collaborative project involving textile designers and manufacturers in Scotland attempting to use design to shift fast fashion towards more sustainable outcomes. The process outlined emphasises the importance of design informed by the whole lifecycle of the intended product, and the role of co-creation in the new economy of end-of-life value creation, or recreation (Sanders & Stappers, 2008).

Taking up both themes explored by the first two essays in this part, that of the consumer's ongoing relationship with their possessions, and that of co-creation in linking production to consumption, the next essay summarises a fascinating design-led experiment conducted by Kirsty Máté, where passing shoppers were encouraged to stop and engage with a range of second-hand or donated objects in more direct, interactive, typically non-transactional ways. This essay, along with the two preceding ones, reminds the reader of how consumers are now 'trained' by advertising, marketing, and peer example, to adopt a linear perspective of the products they buy, as short-lived, packaged products and only of real value when they are brand new, or nearly so, a perspective that is neither natural or unchangeable, but one that can be altered, under the kinds of circumstances Máté manages to briefly create.

This is then followed by an insightful essay by Ruth Lane and Wayne Gumley on where many everyday items presently end up in the linear economy, in charity shops and recycling centres, and how these institutions rather precariously fit into, or link to, the present consumer retail landscape. This essay is drawn from the larger Australian research initiative, 'Wealth from Waste' (Wealth from Waste, 2017), which both authors have been closely involved with, and brings out the way that reuse is now intentionally marginalised in the linear economy, as of a lesser value, for charities, and volunteers to pick up and somehow deal with. The final essay in this section, by Anne Sharp and Vaughan Levitzke and colleagues, takes up this theme using the forensic lens of marketing to gain a closer view of consumer intentions when confronting their own wastes. The essay revisits the waste hierarchy from a consumer behaviour perspective, focussing attention on its most preferred but often neglected behaviours, including 'avoidance' and 'reuse', and testing consumer attitudes towards these in novel ways, so that waste managers might be better informed about how to implement the circular economy in their domain (see also GISA).

This final essay in the second part of the book links to, and introduces, the third part, *Waste and Resource Recovery*. This begins with an essay by Jacob Fry and colleagues on the problem of measuring 'waste footprints', taking Australia as its central case. This attempts to map waste outputs more accurately across Australia by type and destination, a summary of an important contribution to the growing research on 'waste informatics'. This need to more accurately measure waste, is necessarily a critical component in the implementation of the circular economy. From this more abstract overview, the next essay, by Lionel Taito-Matamua and colleagues, returns us again to the role of design in 'closing the loop' to implement the circular economy, but this time from the perspective of 'local' waste. In a fascinating and ongoing design and educational experiment, the authors seek to transform the hugely problematic issue of marine plastic wastes into local objects for tourist consumption on Samoa, using simple, off-the-shelf technologies. Ironically, this takes the wastes tourists themselves are in part responsible for, and turns these into a series of crafted reminders of their visit.

The next essay is again design focussed, by Singh Intrachooto, summarizing a study he and some colleagues led on scrap or waste utilisation in Thai factories, mostly SME furniture manufacturers, a study which again highlights the important role of design in implementing more circular processes and outcomes in this, as in many other, industries. While it seems to show the huge gap between ideal and realisation of *unmaking waste* in Thai industries, it shows again most clearly how waste remains neglected and largely unaccounted for, and undervalued, and thus a lost opportunity that the circular economy promises, again with the aid of design, to remedy. This essay is followed by one by Rita Li and a group of colleagues from Hong Kong, China and Australia on the continuing problem of construction and demolition waste. It usefully introduces this subject by overviewing contrasting national or government approaches to the problem, a subject taken up in more technical detail in the final part of the book. Reading this essay, it becomes clear that it is the work of governments particularly to help correct the failures of the present market that the linear economy has for so long exploited, largely unhindered by regulation or market limitation. The last essay in this part, by Wenchao Ma and Guanyi Chen and colleagues, is again a comparative essay on waste, but this time surveying waste composition in different cities, within differing climatic regions, within China, and their potential treatment. This bookends the essay that began this part, by reemphasizing the importance of waste informatics, of more thoroughly understanding the composition of the wastes being generated so that more might be achieved in their transformation in the circular economy. This greater understanding of waste – and not just in numbers – it should be emphasised, is again an essential pathway for future research: we still do not know enough about waste, about its volumes, varieties and potential uses, to be able to more effectively reuse it as resources, and until this can be more accurately mapped, generating more circular economic activities, systems and technologies will remain more difficult to design for, and implement.

This final essay in the third part of the book, usefully opens up the question of the application of innovative technologies to waste streams, which the fourth and final part of the book seeks to address: *Technology and Systems Innovation*. The opening essay in this final section is by Samane Maroufi and colleagues, focussing on the transformation of more 'difficult' wastes into materials of greater value. This more detailed, and scientific, essay, is based upon work that Veena Sahajwalla and her research group has been undertaking for the last decade, and provides an insight into their methods, now made famous by their work on using tyre wastes to make steel, a patented innovation taken up by steel makers across the world. In this essay, they turn their attention to the question of 'end of life' vehicle wastes, and how these polymers might be used in a similar way. This first essay in this section provides a valuable insight into the transformative potential of *remaking* waste into entirely new materials for production.

While this essay highlights the value of material science in transforming waste materials into entirely new ones, the following essay, by Tim McGinley, highlights the value of IT systems in providing more accurate and useful information and access to second-hand or wasted building materials for reuse. Focussed on the potential use of building information modelling (BIM) systems, in combination with online market systems like e-Bay to more creatively reuse building parts and components, this type of innovation is gaining traction across the construction sector because of its enormous cost- and waste-saving potential. Turning back again to the designed 'front end' of construction, this is followed by Philip Crowther's essay on design for disassembly in construction, which highlights the enormous potential in carbon and material savings of this still neglected but widely understood technology in such a strongly conservative industry. The penultimate essay in this part is again design and technology focussed, a fascinating case study by Peng Sen and colleagues from Tianjin on the extensive water engineering design involved in Tianjin University's new 'green' campus. This essay again highlights the importance of *designing* the circular economy, which is such an important and recurrent theme in this book. The final essay in this part, and of the whole book, is by Abbas Elmualim and colleagues, and returns again to the problem of construction waste, focussing on the still underutilised potential of designing smart prefabricated parts and components into buildings. The greater resource efficiencies and carbon reduction generated from this innovation, and the kind of innovations suggested by the previous essays in this part, confirms again the enormous potential of the circular economy to not only reduce waste and pollution, but to create a practical, and achievable, transitional pathway to sustainability.

A number of recurring themes, emphasised above, can thus be seen in this book. Firstly, many of the essays as we have emphasised, address the increasingly important role of *design*, in reforming or reusing materials, objects, systems and environments into more effective, and more valuable forms of reuse. This design focus or intent spans many of the essays here. Indeed, essays in each part of this book reveal how design cannot remain just an 'idea' informing the circular economy, but lies at the centre of this concept, and must be applied to each domain to reverse the present wasteful flows of resources and energy that have given rise to our environmental crisis.

The second theme that stands out on reading these essays is the importance of understanding and enumerating *waste* itself in more depth, with a much greater degree of accuracy, and in some cases reimagining or reconceptualizing waste in entirely new ways. Wastes are, typically, misallocated resources, whether their potential reuse has been understood and recognised, or not. Without accurately understanding waste's composition, elemental qualities, volumes and locations, implementing the circular economy will remain largely impossible. Knowing what is *in* waste itself, or what might be done to reuse wastes, the subject of several of the essays in the last part of this book, becomes an especially important topic, if the circular economy is ever to be implemented.

Thirdly, the essays in this book are also threaded through with the theme of the importance of the application of *science and technology*, and especially of innovations in materials, processes, products and supply chains, with these all, in their own way, linked back to design. The circular economy's implementation, as many of these essays attest, will require more effective, and innovative ways of applying scientific knowledge and technology, even in relatively familiar contexts.

Another final, but also important theme presented here, is the *interdependence of production and consumption*, which is typically neglected in discussions not only of the circular economy, but in the current discourse on sustainability itself. In the first essay, and in the essays that make up the second part especially, consumption is addressed repeatedly as the shaper and stimulator of our present overconsumption of resources, and of the 'material flows' that make up both the linear, and circular economies. Shaped by design, technological innovation and the pricing of goods, consumption, like design and technology cuts across or influences almost every discussion of wastes, resources, services and their respective values. What consumers want or value shapes their engagement in the economy, and can contribute directly not only to materials chosen for use, but also to what is wasted, and ultimately to the economy's larger environmental impacts.

Involving over 40 researchers from around the world, including many from Australia and China, from both developed and developing nations, this collection of essays is unique in suggesting how the circular economy concept can become a vehicle for transitioning towards a more sustainable society, and how it can also be used as a lens through which more effective responses to now common environmental problems can be designed and developed. From the vantage point of the many disciplines represented here, the circular economy has rapidly become a useful framework for understanding and developing solutions to some of the worst of today's environmental problems.

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Part I

History, Theory and Experience

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Chapter 1

From 'Spaceship Earth' to the Circular Economy: The Problem of Consumption

Robert Crocker

Abstract

In the face of increasing resource insecurity, environmental degradation and climate change, more governments and businesses are now embracing the concept of the circular economy. This chapter presents some historical background to the concept, with particular attention paid to its assumed opposite, the 'linear' or growth economy. While the origins of the circular economy concept are to be found in 1960s environmentalism, the chapter draws attention to the influence of the then 'new' sciences of ecology and 'cybernetics' in shaping the public environmental discourse of the period. It also draws attention to the background of the present linear economy in postwar policies that encouraged reconstruction and a social and economic democratisation across the West, including an expansion of mass-consumption. It emphasises the role of the 1960s counterculture in generating a popular reaction against this expansionary growth-based agenda, and its influence in shaping subsequent environmentalism, including the 'metabolic' and ecological economic understanding of the environmental crisis that informs the concept of the circular economy. Reflecting upon this historical preamble, the chapter concludes that more attention should be paid to the economic, cultural and social contexts of consumption, now more clearly the main driver of our global environmental crisis. Without now engaging more directly with the 'consumption problem', the chapter argues, it seems unlikely that the goals of the circular economy can be met.

Keywords: Circular economy; linear economy; rebound effect; 1960s environmentalism; counterculture; consumption; waste; resource scarcity

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 13–33

doi:10.1108/978-1-78714-619-820181003

Introduction

According to the British charity, the Ellen MacArthur Foundation, the circular economy is a visionary model of an environmentally and socially sustainable economy that is 'restorative by design', aiming 'to keep products, components and materials at their highest utility and value at all times' (EMF, 2013; Webster, 2013). This model envisages a shift away from fossil fuels towards renewable energy, shared product-service systems and also towards a material flow of closed loops in all products, components and materials, not unlike that found in some high-value areas of recycling and remanufacturing today. Enticed by the profits and reduced environmental costs associated with such innovative circular strategies, in this vision manufacturers themselves will be encouraged to become involved in reusing materials and products, thus reducing energy and resource use, materials consumption, pollution and waste (Lacy & Rutqvist, 2015; Webster, 2013).

As promoted by the Ellen MacArthur Foundation, the circular economy concept has been successful in engaging many large corporations and governments into taking the environmental consequences of today's growth economy more seriously. For example, the concept has transformed the once radical ideas of extended producer responsibility and environmental stewardship from external liabilities into potential business opportunities (Lacy & Rutqvist, 2015). The model has the distinct advantage of appealing not only to the bottom line of many large and generally risk-adverse companies but also to the policy choices faced by governments confronting the twin challenges of climate change and the social impacts of industrial transformation. Most importantly, the circular economy concept has helped reframe and give direction to the sustainability agendas of many corporations and governments, worried about the political and economic risks of seeming to slow growth in the name of the environment (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Hughes, 2017; Lakoff, 2010).

By tracing the history of the circular economy back to its genesis in the environmental conflicts of the 1960s, and particularly to the 'circular' resource- and energy-focussed metaphor of 'Spaceship Earth', attention is drawn here to the many ways in which the ideological conflicts of the past continue to shape today's debates about the environmental crisis and what should be done about it (Schor, 2010; Sabin, 2013). As in 1960s environmentalism, the circular economy concept has focussed on our systemic overconsumption of resources and energy, while neglecting the role of the global consumption of goods and services as *in itself* the main driver of this resource depletion, environmental degradation and climate change (Dauvergne, 2008; 2010). The chapter ends with a consideration of the role of design in shaping the continuing expansion and acceleration of consumption and argues that more directly addressing the role of design in the present linear economy could assist in furthering the goals of the circular economy.

Discovering 'Spaceship Earth'

The history of the circular economy concept is often traced back to postwar environmentalism (Deese, 2009; Rome, 2015; Winans, Kendall, & Deng, 2017), although its metaphorical reference to a circle of material flows and energy has been clearly influenced by the natural sciences, and especially biology and ecology, where the word 'metabolism' had long been used as a way of talking about the dynamic interaction and interdependence observed between a living being and its immediate environment (Fischer-Kowalski, 1998). As several writers (e.g., Deese, 2009; Winans et al., 2017) have emphasised, the spaceship metaphor for a 'circular' movement of material and energy flows seems to have first appeared in Kenneth Boulding's writings (1964, 1966), and was then quickly popularised, soon gaining a wide public currency (e.g., Fuller, 1969; Ward, 1966).

For Boulding (1966), contemporary economics was 'cowboy economics' in its lack of engagement with the environment, since its measure of economic success was a one-way throughput of energy and materials, thus leading to the potential loss of natural resources or 'stocks'. This is perhaps one of the first enunciations of the 'linear economy' that we have, and to this Boulding (1966) opposed a notion quite similar to that of the circular economy, a coming 'spaceman economy', a model where throughput would be minimised, and the success of the economy would be measured by the 'nature, extent, quality, and complexity of the total capital stock, including in this the state of the human bodies and minds' (p. 9, in Fischer-Kowalski, 1998, p. 70). Input–output analyses of cities and of national economies, made familiar since this time through the developing discipline of environmental economics, soon followed this physical reformulation of the economy as a series of material and energy flows (Ayres & Kneese, 1969; Fischer-Kowalski, 1998; Røpke, 2004).

Like today's circular economy concept (see Andersen 2007; Pearce & Turner, 1989), the idea behind Boulding's formulation of 'Spaceship Earth' was an optimistic one, suggesting that humanity itself (as the 'spaceman') had the capacity and ability through advancing scientific knowledge to responsibly *pilot* the spaceship of the earth, managing its supplies of water, food and fuel for the benefit of all of its many occupants (Deese, 2009; McQuaid, 2006). This metaphor's widespread popular appeal to a more collaborative approach to the environment can be readily understood by referring to NASA's famous photograph of the earth from space, reproduced on the cover of the first issue of the *Whole Earth Catalog* (Brand, 1968; Turner, 2006), and used to promote 'Earth Day' from 1970 (Poole, 2008; Rome, 2013). This view was deliberately contrasted with the shortcomings of postwar modernist planning, development and industrial and military expansion. In this way, the idea of Spaceship Earth became a way to question the then common assumption that the earth's resources were unlimited, and available for unending exploitation (Sabin, 2013; Turner, 2006; Schor, 2010).

The irony behind what became an emerging ideological struggle is that it was the prosperous and leisurely lifestyle of an educated middle class, enabled by this rapid development, that allowed more people to have the time and space to understand and interact with the natural environment, and especially the picturesque nature that they could now visit in their cars. As a number of historians have noted, the development of a greater popular interest in both preserving and more safely managing natural landscapes ironically parallelled the rise of the car, the suburb and the discovery (or rediscovery) of travel as middle-class leisure activity, especially towards the picturesque, whether in the woods, by the sea, or somewhere far away from the city (Harvey, 2012; Hays, 1987; Rome, 2013). The car, paradoxically, let more people see for themselves the unique beauties of their nation's natural resources.

Thus, the environmental movement which developed in both America and Western Europe after the Second World War was closely tied in to rising living standards and began initially as a relatively conservative reaction to unrestrained development, but became in time increasingly linked to more radical calls for social, economic and political change (Formia, 2017). The perceived threats to the 'good life' to be found in an increasing array of environmental dangers had been identified and publicised by a new generation of postwar ecologists and nature writers (Hays, 1987; Kirk, 2007; Turner, 2006). Higher standards of living, better scientific education and a wider understanding of the outside world through new electronic media, and especially the TV, led to more knowledge of the negative environmental impacts of industrialism and urban development. This led in turn to a more negative view of consumption and its environmental consequences, with 'consumerism' becoming the distinctly ideological term it remains to this day (Crocker, 2016; Swagler, 1995).

Back to the Garden: 1960s Environmentalism

The Counterculture's 'Cybernetic Ecology'

The origin of today's more politically engaged environmentalism is often traced back by historians more specifically to the utopianism and 'back to nature' communalism of the 1960s counterculture (Kirk, 2007; Marwick, 1998; Roszak, 1969; Turner, 2006). Conscious that their age was uniquely democratic, better-educated than their parents, but lacking the constraining experience of war that had shaped the older generation, the counterculture drew particularly on two distinct but complementary contemporary developments. The first was that of the revival in biology and ecology during the 1950s which was made available to them through popular writers and campaigners like Rachel Carson (1962) and Barry Commoner (1971) (see Egan, 2002). These drew attention to the extraordinary damage modern chemical agriculture and rapid industrial development were wreaking on the natural environment. Their view found ready allies amongst many scientists, including those worrying about the likely effects of rapid population growth, a concern popularised (and probably overstated) by Paul Erlich (1968) in his popular Malthusian jeremiad, *The Population Bomb*. This book enjoyed a huge following at the time, and like the anxieties generated by the nuclear threat of the Cold War, seemed to help justify the counterculture's back to nature communalism. But its scare-mongering was disliked by many scientists, who saw it as unduly apocalyptic and, in many respects, fundamentally misleading (Egan, 2002; Sabin, 2013), with Commoner himself one of Erlich's most notable critics.

A second significant influence on the counterculture's 'ecological' vision of the world and humanity's relationship to it emerged from the social dimensions of the new technologies of the period (Kirk, 2007; Turner, 2006). The TV, records, cheap paperbacks and pop music paradoxically enabled a widespread questioning of the 'technocratic society' itself (Marwick, 1998; Roszak, 1969), and the Cold War and Vietnam War (Mercer, 2011; Zimmerman, 2006). The young were growing up in a world of new, accessible and cheap communication technologies, the transistor radio, the portable record player, the TV and the first microcomputers, each promising a new expansion of personal freedom, knowledge and experience seemingly denied to their parents, and to those who allowed others to decide what they should see, experience or understand (Roszak, 1969). They became 'natives' to this new electronically mediated world and privy to its promises and fears, 'technological natives' intent on making the most of these new 'tools' for self-discovery and self-expression (Binkley, 2007).

The microcomputer or 'personal computer' seemed to promise a new kind of freedom to this generation (Turner 2005), and 'cybernetics', Norbert Wiener's (1948, 1954) earlier influential explanation of computational systems theory, was embraced as a key to understanding this larger revolution in technology and its promise to 'augment' human intelligence and ability (Rid, 2016). Douglas Engelbart, the Stanford engineer responsible for the so-called 'Mother of All Demos' at the 1968 annual Californian Computer Conference in which he and his team demonstrated most of the now familiar elements of the personal computer, including windows, mouse, graphics, hypertext, word-processing and even email, was greatly influenced by these ideas, believing that the 'memory machine' he was trying to create could augment expert problem-solving (Engelbart, 1988). It is perhaps not surprising that Stewart Brand, the prominent counterculture leader and editor of the *Whole Earth Catalog* (1968) was a great fan, and was present, and helped Engelbart as an assistant, during this now famous 'Mother of All Demos' (Turner, 2005).

The San Francisco counterculture poet, Richard Brautigan, spoke for the utopianism of his generation when he tried to bring these two sources of new and potentially revolutionary forms of knowledge together, calling for:

> a cybernetic ecology, where we are free of our labors, and joining back to nature, returned to mammalian brothers and sisters, and all watched over by machines of loving grace. (Brautigan, 1968, cited in Kirk, 2007, p. 107, and also in Rid, 2016)

This utopian belief that the computer's ability to solve the problems of the world could result in actions that might prevent environmental damage and even war itself, fed back into a growing scientific interest in the predictive 'metabolic' modelling referred to above, and to the beginnings of ecological economics (Røpke, 2004), with one of the most influential instances of this being the Club of Rome's report, *The Limits to Growth* (Meadows, D. H., Meadows, D. L., Randers, & Behrens, 1972; Meadows, D. H., Randers, & Meadows, D. L., 2004).

While it may be true that many of the counterculture's ideas can be found in the publications of late nineteenth- and early twentieth-century nature writers and reformers (Delveaux, 2006), they had dramatically updated these older ideas. Non-monetary exchange, the localisation of economic activities, the idea of do-it-yourself making and consuming (now termed 'prosuming') and the spiritual and moral benefit of making things by hand, and with others ('do-it-together'), were all rediscovered and given a technologically enabled makeover, in keeping with the hopes and fears of the time (Binkley, 2003, 2007; Turner, 2006). Avidly reading and listening to the prophets of the 'small', the 'local', and communal, from the farmer poet, Wendell Berry, to the radical economist, E. F. Schumacher (1973), and the engineer and inventor, Buckminster Fuller (1969), the counterculture embraced what seemed at the time to be 'lost' alternative forms of knowledge (Roszak, 1969), with these increasingly shaped by the central 'metabolic' or ecological-economic idea of Spaceship Earth. The extraordinarily successful *Whole Earth Catalog* (produced between 1968 and 1971), subtitled 'Access to Tools', was avidly embraced by hundreds of thousands of young people across the Anglophone world, from the late 1960s onwards (Anderson, 2012; Binkley, 2003, 2007; Turner, 2006).

Designing with Nature

A third related influence on 1960s environmentalism, also evident in the counterculture, which again has shaped much of today's sustainability agenda, along with that of the circular economy, can be found in architecture and design. This 'alternative' design movement saw the environmental crisis, and the social and urban crises that seemed to accompany it, as primarily a 'design problem', the result of an ongoing misuse of technologies, resources and environments for short-term, but ultimately self-destructive, financial or political gain (Formia, 2017; Kirk, 2007; Turner, 2006). As well as the influential ideas of Buckminster Fuller (1969), a number of other significant voices contributed to this design-led attack on technocratic postwar industrialism and modernist-inspired development. Memorable voices in this movement towards 'ecological design' were those of the landscape architects, Ian McHarg (1969) and John Lyle (1992), whose ideas gave rise a bit later to McDonough and Braungart's now famous 'cradle to cradle' approach (2002), which has in turn influenced the circular economy concept (EMF, 2013), and the prominent counterculture architect Sim van der Ryn (1978), who was one of the first to advocate the incorporation of renewable energy generation, water conservation techniques, reused materials and passive solar design in all buildings (see also Anderson, 2012). Another very significant figure in this opposition to postwar technocratic design and planning was the farsighted journalist turned urbanist activist, Jane Jacobs (1961), whose powerful anti-modernist critique is still influential amongst planners and architects today (Flint, 2009).

Despite significant individual differences, the voices of these young designers were united in questioning the assumptions of an earlier generation of modernist masters, or at least how their ideas had been taken up and applied by governments, corporations and developers in the 1950s and 1960s. Their mission, variously defined, was to shift the priorities of planners, architects and designers back to designing *with,* rather than *against*, nature, place and community (Formia, 2017; Papanek, 1971). They were not anti-technological, but rather critical of the commercialised misuse of technology. For example, Victor Papanek's now widely cited critique of modern industrial design, as the ultimate enabler of consumerism and waste (1971, pp. xi ff.), was focussed on the routine misapplication of design for short-term gain, a critique similar to Buckminster Fuller's, and a theme that has been mined in sustainable design discourse ever since (e.g., Fuad-Luke, 2009; Thorpe, 2012; Walker, 2011). The solutions Papanek proposed are also now familiar features of the circular economy, including the requirement to design more durable products (Cooper, 2010), and ensuring that more complex products like cars and industrial equipment be leased rather than individually owned (Vezzoli, 2013).

Recycling and Reuse

A fourth important early line of descent from postwar environmentalism, and one which has also influenced the circular economy, and echoes many of the same preoccupations scattered through the *Whole Earth Catalog* (1968), was a rediscovery of the value of recycling and reuse (Macbride, 2011; Van der Ryn, 1978). This emphasis on reuse was strengthened also by those 'Malthusian' environmentalists like the Erlichs who predicted future shortages of resources and fuels, if unrestrained growth was allowed to continue (Egan, 2002; Sabin, 2013). The emphasis placed on reducing resource use and waste again stimulated a rapid expansion in the modelling of resource use with the aid of the new computers, and a greater interest in how industrial production itself might be modified and placed on a safer, more environmental footing (Cato, 2009; Meadows et al., 1972).

Deliberately reusing wasted energy or materials again, as potential resources for making other goods or in other industrial processes, became important topics in their own right in the early 1970s (Palmer, [1978] 2005). In a process now termed 'industrial symbiosis', materials could move from production to consumption to waste and then themselves become resources for new processes, in this way contributing to production again (Frosch & Gallopoulos, 1989; Lehmann & Crocker, 2012; Stahel, 2010). Taken up as an essential principle in Walter Stahel's earlier work (1966, 1997; Stahel & Reday, 1976), and then represented in McDonough's and Braungart's *Cradle to Cradle* (2002), this notion of a second technical, cycle of material and chemical flows, parallelling and potentially mimicking, that observed in nature, became in turn a foundational concept in the circular economy (EMF, 2017).

A much-studied early exemplar of this type of industrial symbiosis of materials and energy production was the industrial park of Kalundborg in Denmark, which grew incrementally from an industrial precinct in the 1960s, into a symbiotic network in the 1970s, into one of the world's first 'eco-industrial parks' in the early 1980s, with a number of larger companies exchanging waste energy, water and materials on-site, encouraged by the local municipality (Jacobsen, 2006). Providing a case study for industrial ecology, and a demonstration site for how a circular movement of energy and materials within one precinct might occur, Kalundborg had a particularly significant influence on China's take up and implementation of the circular economy concept (Zhao, Chapter 3, this volume; Yu, Han, & Cui, 2015; Zhang & Barr, 2013). Such an industrial 'metabolic' vision of managed circular material flows has in turn stimulated a growing body of research into the potential transformation of logistics and supply chains in many industrial sectors (see Elmulaim et al., Chapter 19, this volume), and also into the more elemental 'reformation' of chemicals, metals, plastics, oils and sludge, and their potential reuse in other forms (see Goh et al., Chapter 4; Ma et al., Chapter 14; Maroufi et al., Chapter 15, this volume). As this suggests, a large and developing body of knowledge and industrial effort has now become engaged in what might be loosely termed circular economy-style materials reuse and supply-chain management strategies (Zeng, Chen, Xiao, & Zhou, 2017). This is perhaps the most successful descendant of 1960s environmentalism that the concept of the circular economy has lent itself to, and one where significant research can be expected, especially in Europe and China (see Su et al., 2013; and Zhao, Chapter 3, this volume).

The Postwar Political Economy

The lines briefly drawn, above, from 1960s environmentalism to the circular economy, through the environmental crisis of the 1970s and the debates it engendered (e.g., in Sabin, 2013), would make little sense without a recognition that many in this earlier period were responding for the first time to the dramatic surge in population growth, urban development and mass-consumption that followed the Second World War (Pfister, 2010; McNeill, 2010; McNeill & Engelke, 2014), and were seeing evidence for this, no doubt intensified by the fears engendered by the Cold War, for the first time on TV. Reconstruction and democratisation – as the twin pillars of western economies in the postwar era – necessarily involved attempts to transform the wartime economy into a new democratic, and deliberately consumption-oriented, direction. In Europe, this was bolstered by the Marshall Plan, an attempt by the US government to ensure a return to employment and economic stability after so many years of destruction and destitution (Crowley, 2008; De Grazia, 2005; Pfister, 2010). This was aided by the use of abundant and cheap oil, and a rapid shift from coal to oil as the primary energy fuel, with the motor car, its manufacture and often extensive infrastructure, becoming the prime mover of economic recovery in many nations (Black, 2012; Pfister, 2010). This expansion of the oil and automobile industries generated a more mobile society – in both spatial and social terms – with a number of important implications for traditional social and economic relationships, towns and communities (Patterson, 2000; Pfister, 2010; Soron, 2009). 'Slums' were identified, often controversially, and 'cleared', sometimes against the will of their own residents (e.g., in Jacobs, 1961), and cities were remade to become more 'car-friendly', with the planner, architect and civil engineer becoming the agents of technocratic modernisation (Flint, 2009; Lundin, 2008).

The widespread belief in many Western government circles was that without a noticeable improvement in living standards, the West might lose its 'economic war' against its Soviet enemies, even if it managed to maintain military parity (Cohen, 2004; McNeill, 2010). Military modernisation, agricultural modernisation and industrial modernisation all contributed to an economic 'long-boom' and the emergence of a global mass consumer society (Maddison, 2006; McNeill, 2010; McNeill & Engelke, 2014). Government-led investment in infrastructure and planned modernisation included social investments such as subsidised housing, health care, agriculture and free or more accessible education (Marwick, 1998; McNeill, 2010; Pfister, 2010).

A larger vision of remaking the world along more democratic and technocratic lines aided by expanding consumption had a number of additional social and material impacts (Crowley, 2008). For example, the focus on scientific, technological development and growth made the expansion of higher education a priority, with design, engineering and applied science all rapidly expanding during the 1960s, and each nation building new universities to accommodate more students, especially in these disciplines (Marwick, 1998). From being the creed of a small band of avant-garde architects and designers in the 1920s and 1930s, modernism became the dominant approach to design, influencing planners, architects and designers for a generation. Indeed, modernism not only transformed architecture and design in the city but also became a vehicle for Cold War propaganda, as designers put together sometimes lavish travelling exhibitions to promote the modern, democratic, American way of life (Masey & Morgan, 2008; Pavitt, 2008).

Designers, for their part, were encouraged not only to produce more affordable goods and homes for 'everyone', but also to adapt new technologies and materials for democratic purposes, especially in the domestic sphere (Kirkham, 2009; Marcus, 1998; Meikle, 2005; Pavitt, 2008). The home, along with its kitchen, and a changing array of appliances, emerged as a symbolic Cold War frontline, representing the 'good life' that citizen-consumers in the West were supposed to one day be able to enjoy (McDonald, 2010; Oldenzeil & Zachmann, 2009; Parr, 2002). Whirlpool's Miracle Kitchen, for example, presented on TV in America from 1957, was toured to Western Europe, becoming one of the three new American kitchens on display in the Moscow American National Exhibition of 1959, which became the setting of the famous 'kitchen debate'. Watched by millions back home, Nixon recorded his encounter with his Russian counterpart, Nikita Khrushchev, on TV, arguing for the superiority of the American way of life, where 'anyone' in the West might own the home on display, including its modern kitchen (Marling, 1995; Oldenzeil & Zachmann, 2009).

A little earlier, in 1955, Victor Lebow, an American economist and marketing expert, in an essay placed in the *Retail Magazine* of 1955, had argued that American industry could only avoid the economic dangers of the interwar years by continuously stimulating consumption as a key to economic growth (Cohen, 2004; Maddison, 2006). In a frequently cited passage from this essay, he declared:

> Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfactions, our ego satisfactions, in consumption. The measure of social status, of social acceptance, of prestige, is now to be found in our consumptive patterns. The very meaning and significance of our lives today are expressed in consumptive terms…. We need things consumed, burned up, worn out, replaced, and discarded at an ever-increasing pace. (Lebow, 1955, p. 7)

Democratisation, and a technocratic expansion of the state through largescale social and infrastructure investments, created an ideal setting for a booming postwar consumer economy, with full employment all but guaranteed by continuous economic expansion. Economists became the de facto engineers of this growth economy, much to the chagrin and concern of Boulding (1966), Schumacher (1971) and other early 'green' or 'alternative' economists (Cato, 2012; see also Shanahan, Chapter 2, this volume).

The goal of this political and social democratisation, and its dependence on mass-consumption, also favoured the largest producers and retailers (Shell, 2009), and began the gradual shift from a society of mass-producers to one of mass-consumers that marked the second half of the twentieth century (Smil, 2013). Selling more goods to more consumers, and more often, in these years became the organizing principle of postwar design, marketing and retail, especially from the mid-1950s (Marcus, 1998; Pavitt, 2008), when it seemed that progress itself, and the 'good life' it promised, depended upon continuous economic expansion (Cohen, 2004; Crowley, 2008). Continuous growth would guarantee higher living standards, and thus avoid the kind of social and political upheavals of the past.

Diminishing Returns and Increasing Volumes

During the 1970s and 1980s, a revolution occurred in the ability to deliver goods to consumers everywhere, a revolution led in part by trade globalisation and the continuing computerisation of industry and transportation (McNeill & Engelke, 2014; Schor, 2010). This can be seen in US trade data, where a steady increase in the volume of imports in many categories is recorded, especially during the 1990s and 2000s, with individual prices of goods, per unit, on average falling over the same period (Schor, 2005, 2010). In clothing, appliances, computers and mobile phones, Juliet Schor finds a similar story, with increases in the recorded volume of imported goods ranging from 50% to 200% (with the exception of mobile phones, which increased 1000+ %, and of laptops, which increased in the 600% range). During this period, there was a significant drop in the relative prices of these same items, ranging from 10% to 50%, especially from the mid-1990s (Schor, 2010).

During this same period, the lifespan of many goods also fell, with universal credit enabling a further extension of the average consumer's disposable income, increasing their buying capacity, to purchase, and waste, more goods, and more often (Penaloza & Barnhart, 2011). It became possible to sell the same or very similar goods to the same customers more frequently sometimes reselling slightly updated products, tempting them with new designed capabilities, new packaging or other variations in their appearance (Slade, 2006). This strategy of selling more goods more cheaply to more people, and more frequently, has an obvious and immediate advantage to those large chain stores that early embraced this business model (Shell, 2009). It also has a profound impact on the environment, with McNeill and Engelke (2014) rightly calling this a 'great acceleration' for its dramatic effects on rising greenhouse gas emissions.

Drawing attention to the Jevons paradox or rebound effect today has become an important means of arguing against the more optimistic idea of 'green growth', that shifting energy and production towards lower impacts through technological innovation and greater eco-efficiency will result in a 'decoupling' of economic activities from material flows (Verbeek & Slob 2009; Dahmus, 2014; Magee & Devezas, 2016; Zink & Geyer, 2017). Certainly, there is a fundamental logic behind the proliferation of things that has marked the postwar era: more efficient mass production has generated much larger volumes of cheaper goods, and these have become affordable to more people. These in turn must be sold, and then sold again, since the margins each item might yield diminishes with the overall reduction in prices technical improvements allow. Diminishing returns per unit require more intensive measures to sell more units to more people, and faster, or technical innovations to increase returns in some other way. For example, the coffee pod jumps over the obstacle of diminishing returns by turning a cheaper everyday staple into a more expensive (and, initially, proprietary) 'convenience'. Thus, the logic of growth itself suggests both the need to increase volumes for sale, while also increasing where possible a frequency in sales, which necessarily requires a greater frequency of disposal. In this way, more room can be made for the new, the latest and the marginally better (Campbell, 2015; Schor, 2005, 2010). Consumer tastes through marketing can also be encouraged to change, in this way increasing demand for the same products, but enhanced with additional features or stylistic innovations.

For example, as Smil points out (2014, pp. 130–135), there are some instances where efficiency increases in production and distribution fail to result in the dematerialisation that might be predicted from overall industrial trends. In these situations, the expected monetary 'savings' from technological improvements have not occurred, but are 'spent' – through apparent choice – on over-engineered or unnecessary additional accessories or technical features. Smil uses the take-up of SUVs over the last two decades to argue this point, for in this instance product and process improvements have been 'wasted' on market-driven design innovations, including unnecessary increases in the size, weight and power of the vehicles themselves (see Rollins, 2006). In contrast to the optimisation to be seen in the history of aircraft, where consumers have little choice, this example suggests that care needs to be taken in attributing so much to the Jevons paradox or rebound effect, at least without considering the dynamic role of design and associated business models, and their ability to encourage more consumption.

Designing the 'Good Life'

Design and marketing have often had a dynamic impact on consumption, generating novel products, or services which can rapidly expand consumption volumes and shift consumer practices into new, and sometimes prodigiously damaging channels. While this is now increasingly recognised (e.g., in Bocken, de Pauw, Bakker, & Van der Grinten, 2016; EEA, 2017; Hughes, 2017; Tecchio, McAlister, Mathieux, & Ardente, 2017), policy and legislative initiatives that might limit or contain this situation are still too rare. In briefly outlining the three recent historical examples given below, the intention is to again underline the central role that design and marketing can play in generating environmentally damaging consumption patterns, beyond those that might respond to increases in efficiency and lower prices.

Plastics and Furniture

Plastic was not just a new material, but embodied the promise of a better life in the 1950s and 1960s, a future of greater prosperity and leisure that consumption itself came to promise (Freinkel, 2011; Meikle, 1995, 1999). Its low price, multiple uses and implied technological advancement made it a somewhat ambiguous emblem of everything modern (Meikle, 1995). Films like Jacques Tati's comedy, *Mon Oncle* (1958), where his hero, Monsieur Hulot, for example, goes to work in a factory named *Plastac*, speak directly of this ambiguity and its power of suggestion. In this film plastic (somewhat like concrete in the same period) is the central symbol of a new technologically enabled modernity, but one that was at the time unprecedented, and thus evoked considerable anxiety across Tati's native France (Smith, 2007). Since it lacked the historical qualities associated with other materials such as wood or steel, it seemed a cheap substitute that 'borrowed' its identity initially from the materials it came to replace (Manzini, 1993). Designers, however, revelled in the possibilities of this new miracle material and the expressive freedom it enabled (Meikle, 1995), in this way further fuelling consumerism.

To take a related example, although the foam now commonly used in upholstery was at first regarded as a likely substitute for other materials, its own qualities soon led to entirely new designs. For instance when Gaetano Pesce designed his 'Up' series of pop-up foam armchairs and stools for C&B Italia in 1969 (Fiell & Fiell, 2006, pp. 536–537), these entirely foam armchairs came vacuum-packed in airproof plastic film, and then slowly attained their striking bulbous forms on exposure to the air. Other plastics invoked similarly radical design treatment, with the first (sewn leather) beanbag filled with then novel polystyrene balls, defining in its own way a new 'way of sitting' (Furlanis, 1998). Other radical departures based on novel uses of plastics can be seen in the thick airproof films used in inflatable armchairs in the late 1960s, and in several experimental 'blow up' buildings designed in the same period, but, perhaps fortunately, rarely constructed (Furlanis, 1998; Meikle, 1995; Sparke, 1988).

Emblematic of the throwaway society of the 1960s, the plastic chair in its various guises, along with the beanbag, the blow-up or pop-up armchair, were designed to be bought to bring colour and glamour into the more democratic low-cost late-1960s interior, to be used for a time until, perhaps, the foam began to soften or give way, seams ruptured or legs broke, never to be repaired (Fiell & Fiell, 2006; Whiteley, 1987). In the new expressive and flexible home, furniture was not only cheaper but designed to be short-lived, more lightweight and easy to dispose of, once the user's 'lifestyle', situation or desires, changed. Like the Italian designer, Joe Colombo (Favata, 1988), many designers in this period made the point that self-expression entailed a provisional status in many possessions, especially in the domain of the interior, where consumers might want different things at different stages in their lives (Whiteley, 1987).

A very similar creeping 'flexibilisation' can be seen in the kitchen and dining room, in lighting and textiles and also in automobile manufacture, which began in this period to incorporate more and more plastics, and 'lifestyle options', notably in car bodies and interiors (Meikle, 1995; and see Maroufi et al., Chapter 15, this volume). Plastics, in many ways, became *the* expressive material of consumer democracy, always modern or up-to-date, flexible, colourful, egalitarian, cheap, but also short-lived in use, and never to age gracefully or to even decompose (Eriksen, 2014; Geyer, Jambeck, & Law, 2017). Indeed, it is only a short step from 1960s' interiors to today's IKEA, with its replaceable but short-lived flat-packed furniture (Hartman, 2007). Indeed, IKEA's expansion from a local Swedish store into a global giant really began with this 'democratisation' and 'flexibilization' of the interior in this period.

Single-Use Products

Plastics not only became substitutes for once more expensive and scarcer materials, but because of their low cost and ease of manufacture, could further a democratised acceleration in consumption by radically lowering prices in many other domains, from furniture to kitchenware, carpets, textiles and clothing (Meikle, 1995, 1997). One of the most notable effects of the gradual postwar increase in volumes of goods sold and the relative decline in their prices (Schor, 2005, 2010), was the competitive pressure this placed on company margins, which in turn drove more to rely on design and marketing to maintain their market share, and to increase their turnover, as the quote from Lebow (1955), above, suggests. More efficient manufacturing processes could deliver more goods more cheaply, but this typically lowered the margins of each unit sold, requiring the sale of more, and the more rapid disposal of what was sold, and their more frequent replacement.

Pioneered by the 'barons of cheap' in the early years of the twentieth century, and further perfected through branding, mass-marketing and computerised stock control evident in giants like K-Mart, Walmart and IKEA today (Shell, 2009), costs could be even further reduced not just by material and process substitutions, but by scaling up production and buying in bulk, and where possible reducing the useful life of what was being sold through various design and marketing strategies. For example, small items could be packaged together in single-use containers or small bundles, and these might be products that most consumers needed, such as everyday cosmetics, sanitary and grooming products. This encouraged consumers to return to replace what they had bought sooner.

A notable recent example of this fast-moving world of cheap or 'free' products, in this case packaging an everyday drink for takeaway for convenience, is the single-use coffee cup, which in many respects exemplifies a growing single-use category (Ertz, Huang, Jo, Karakas, & Sarigullü, 2017; Ferreira, 2017; Hakkinen & Vares, 2010; Paglia 2014). Adapted from the much older paper cup, single-use coffee cups commonly combine a plastic-lined paper cup with a thin recyclable plastic lid, ensuring that little can be done with this product on disposal, since two different, and expensive, processes would be required to recapture and reuse the different materials the 'set' contains (Ertz et al., 2017; Ziada, 2009). Having multiple advantages in use, suiting today's increasingly mobile, 'on the run' lifestyle, and being extremely cheap to manufacture, and of course offering a valuable surface for various forms of visual promotion, these 'free' cups have moved over the last two decades (since Starbuck invented this 'set' in 1987) to becoming one of the most significant forms of litter in many big cities. Starbucks in the USA alone requires over eight million every day, and it has been estimated that up to 500 billion are being consumed globally each year (Keepcup, 2017). From the provider's viewpoint, these containers have the immediate advantage of enabling more people to drink coffee than can be accommodated within a typical cafe, and can also free the product to be sold at mobile or very restricted locations. Indeed, a cafe with only 10 tables can now serve hundreds of coffees per day with these cups. In this way, a business model that requires a deliberate waste-making has been built around innovative design, making it so much harder for governments to contain or manage (Liboiron, 2013).

Smart Phones

As the two examples above suggest, design and marketing can 'force' growth, above and beyond the power of increasing efficiencies in production. This forcing becomes especially apparent in the world of mobile devices and electronic goods. For example, in an often-quoted figure, on the first day of sales in 2010, at the height of Apple's iPhone success, 1.5 million new iPhones were sold, with 77% going to people who already owned an iPhone (Kim & Paulos, 2011). In other words, by 2010 the mobile phone was being sold with the assumption that most users would *want* or *need* to upgrade, and discard or pass on their existing phone soon after the new version had appeared.

To put this in a broader perspective, the mobile phone's lifespan had by this stage been reduced from an average of around 3–4 years of retention in the late 1990s, to between 18 months and a year in 2010 (Crocker, 2012). As this suggests, the average 10-year old child in 2010 might be predicted to need upto 40 mobile phones during the course of their lives, in contrast to the child of the late 1990s, who might have been predicted to need only 20–25 (Crocker, 2012). Rapid upgrading and built-in obsolescence can vastly increase the material flows associated with any given product, however efficiently produced, intensifying a technological rebound effect, again underlying the importance of better managing or restricting linear business models through instruments like the carbon taxation urged for many years by Walter Stahel (2010) and others.

The role of marketing in such transformations in consumption practices has been studied in increasing detail. For instance, Spinney, Burningham, Cooper, and Green (2012) examined a then new but now widespread marketing strategy in the mobile phone market, where a certain European service provider offered a new 'free' phone to their customers each year, in exchange for them signing a new contract. In their study, Spinney and colleagues (2012) emphasised that the availability of this more frequent upgrading also generated a 'destabilisation' in the user's subjective relationship to the mobile phone already in use, encouraging the consumer to sooner look for a new one. In this instance, as in the example of coffee cups, the business model and associated marketing strategies encourage more frequent consumption, with a consequently more intensive impact on the environment.

Smart phones are prime examples of a product with an extremely heavy environmental footprint, but one which could be reduced by changing the prevailing business model and design approach to a product service system, or an internally upgradeable product, rather than the present rapidly obsolescent standalone item that seems to require – through marketing and design – such frequent upgrading (Suckling & Lee, 2015). In reality, the mobile phone is now simply the gateway to a networked service, a gateway that could be redesigned to become the material component of a service rather than its end-point (Vezzoli, 2013), or to become a more valued, longer-term possession (Cooper, 2010). Without government intervention, perhaps combining legislative limits and some financial encouragements, it is very unlikely this will occur.

Conclusion

As the discussion in this chapter suggests, today's failure to grapple with the 'consumption problem' is not new and can be found in almost every material domain (Dauvergne, 2008, 2010). The failure to attend to the economics of consumption apparent in 1960s environmentalism has continued to this day in every area of environmental concern and is certainly not unique to the circular economy. This is partly because of a historical bias in 1960s environmentalism towards saving resources and energy while avoiding waste and pollution. This has resulted in consumption being treated as simply a by-product of production, with certain calculable negative effects produced along the way. This *productivist* bias, focussing on measuring resource flows, has paradoxically helped to black-box the way consumption continuously grows, and dynamically interacts with, and impacts upon, the environment. It has also helped conceal the significant role of design and marketing in forcing, accelerating and expanding forms of consumption that negatively affect the environment, sometimes dramatically (Julier, 2014). In this way, products like the plastic bag and PE-lined paper cup, or the toxic materials used in electronic goods, can seem to suddenly appear as a global problem, before most jurisdictions can formulate an effective response.

A lack of engagement with the everyday economics of the linear economy amongst those interested in the circular economy's implementation and tendency for companies and governments to avoid interfering with businesses until *after* there is evidence that they might damage the environment, generates what can be described as a *postcautionary* approach to production for consumption (Crocker, 2016). Indeed, most volume-based environmental problems, such as those described here, seem to be acknowledged or dealt with only *after* they have been documented to become serious environmental problems, which may be too late (Paull, 2007). While this *postcautionary* approach is beginning to change, and the EU has started recommending guidelines for the design of many new products, and has started linking together various regulations covering resources and wastes (Hughes, 2017; Tecchio et al., 2017), there is still a long way to go before the consumption problem described here will be addressed, and more directly incorporated into the circular economy's implementation.

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Chapter 2

Can Economics Assist the Transition to a Circular Economy?

Martin Shanahan

Abstract

This chapter focusses on the links between economic ideas, sustainability and the circular economy. Economics begins with the view that all resources are scarce and careful and informed choices must be made to ensure resources are used efficiently and not wasted. Given the fundamental importance of markets to human resource allocation decisions, unless economic concepts, especially markets and prices, are used to help transition towards the circular economy, a sustainable economic growth process is unlikely to be achieved. Economists have long grappled with the problems of resource depletion, unsustainable growth and intergenerational equity. Their ideas and views about the interconnection between markets, the environment and resource use have been in existence for several centuries. While frequently overlooked, some of these ideas have important insights for sustainable development and the implementation of a circular economy. The chapter will consider how economic concepts could be used to help society transition to a circular economy. It will also argue that difficulties with the implementation of a circular economy lie less with the application of economic instruments, and more with the political and institutional constraints that reduce our ability to think creatively and innovatively about 'cradle-to-cradle' processes.

Keywords: Markets; prices; behaviour; institutions; political economy

Introduction

The key motivation that underpins the idea of a circular economy is the finite capacity of 'spaceship earth' to sustain ourselves and future generations from the ultimately, limited physical resources (Boulding, 1966). It is argued that

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 35–48

doi:10.1108/978-1-78714-619-820181004

transitioning to a circular economy, one that moves our use of material resources from a linear 'make-use-discard' process, to a 'make-use-reclaim-remake' circular process, is critical if we are to exist sustainably on the planet (Stahel, 2010, 2016; Stahel & Reday-Mulvey, 1981). Central to the notion of a 'circular economy' is a perspective that the production of material goods and their components should be envisaged as a series of circular paths, where elements are used multiple times, and in multiple ways. The concept is akin to the cycles found in nature, such as the carbon cycle, that ensures sustainable growth over time.[1] The ultimate aim is to maintain our natural capital stock so that future generations can also enjoy and sustain life on earth (Ellen MacArthur Foundation, 2012; 2013; 2014; 2015).

To date, much of the literature discussing the circular economy can be broadly categorised into one of three types (Lieder & Rashid, 2015; Winans, Kendall, & Deng, 2017). The first category has focussed on engineering, design and logistics issues and some of the practical problems that need to be addressed to implement such a production system (Andrews, 2015; Bermejo, 2014; Bilitewski, 2012). The second major thread has examined specific cases; where individual products or industries have begun moving from linear production methods to systems more closely aligned with cradle-to-cradle or biomimicry production processes (Hu, Xiao, Zhou, & Deng, 2011; Lieder & Rashid, 2015; Ma, Hu, Chen, & Zhu, 2015; Zhu, Geng, & Lai, 2010). The third category of research has discussed more broadly, the gradual increase in awareness of cradle-to-cradle production and the rising profile of a circular economy. The papers in this last group frequently review the regions where the idea of a circular economy have been most discussed, such as the EU, China and Japan (Ellen MacArthur Foundation, 2015; European Commission, 2014, 2015; Geng, Sarkis, Ulgiati, & Zhang, 2013; Gregson, Crang, Fuller, & Holmes, 2015). Perhaps surprisingly, there are few papers addressing the social transformations needed for the circular economy to be widely accepted, and even fewer that suggest ways to embed the circular economy into everyday social practice (Murray, Skene, & Haynes, 2017, p. 376).[2] Many papers, however, comment on the lack of progress towards the adoption of a circular economy.

This chapter aims to partially address this oversight by highlighting the important role economics can play in assisting the transition to a circular economy. Just as the circular economy can be viewed as part of the transition to a sustainable production system, so economic instruments are a necessary part of the transition to the adoption of more circular production processes (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). The argument put forward here is not that economics can, by itself, result in the creation of a circular economy. Too many attitudes and institutions need to change for economics alone to be the 'answer' to its adoption.[3] Rather, this chapter argues that not only can economic tools be used to help the transition towards a society that recycles its resources more completely but that without these tools it will be almost impossible for a widespread adoption of a circular resource use to occur. The power of markets, price signals and economic incentives must be harnessed if society is ultimately to attain the sustainable circular economy.

Economic Thought about Limited Resources

Economics has, as a central tenant, that all resources are scarce (Parkin & Bade, 2016). A necessary consequence of this is that ultimately people must choose between different outcomes, as they cannot have everything. Economics, by systemizing the cost of any choice (including a nonchoice) – as the value of the next best alternative foregone – aims to allow individuals and markets to make efficient (output maximizing) decisions. The ultimate aim of this approach is to ensure the maximum amount of production, use or allocation from a scarce resource, and so allow (potentially) the maximum number of people access to the benefits of the scarce resource. This can include future generations.

A second (less widely discussed) idea in economics is the interconnectivity of markets (including input markets). Although this notion is implied in economic terms such as 'relative prices', and 'general equilibrium' at its core, recognizing that markets are interlinked means understanding that changes in even one area (including the natural world), will impose costs and benefits on other areas. The human-made commercial environment, therefore, is not only intensively interconnected within itself, it is deeply connected to the natural world – through the resources the natural world supplies, the goods the market produces and distributes, and of course, the very environment that surrounds and sustains humankind. Ultimately, both human and natural capital are intimately and fully connected. This is true for every individual, community and country in the world. Changes in human markets can thus impact on the natural world in many intended and unintended ways.

Yet another concept fundamental to economics, and one that was observed early in the discipline's emergence, was the finite availability of land (later interpreted to include all natural resources). This ultimate limit was the key assumption underpinning the predictions by Thomas Malthus (1798) that the human race would ultimately exist at a subsistence level, as this was the long-run steady state constrained by the limits of nature. While new resources (i.e., including land and later natural resources) and then technology pushed out nature's constraints, only half a century later J. S. Mill (1848) recognised that even these solutions would eventually be subject to diminishing returns, as more effort and resources were required to produce from increasingly marginal land.

> With every rood of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or natural pasture ploughed up, all quadrupeds or birds which are not domesticated for man's use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out, and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture. If the earth must lose that great portion of its pleasantness which it owes to things that the unlimited increase in wealth and population would extirpate from it, for the mere purpose of enabling it to support a larger, but not a better or happier population, I sincerely hope, for the sake of posterity, that they will be content to be stationary, long before the necessity compels them to it. (Mill, 2001, p. 116)

William Stanley Jevons (1865) directly addressed the question of resource depletion (a fundamental assumption underpinning the notion of the circular economy) when he considered the inevitability of Britain exhausting its coal reserves. Several of his observations remain pertinent to contemporary debates on resource depletion. First, the economic depletion of resources (when it becomes uneconomic to continue to extract the resource) will occur before the actual physical depletion of the resource. Second, technological solutions designed to use the resource more efficiently (and so lessen demand) will actually achieve the opposite result (this is now called the Jevons paradox). By improving the efficiency of resource extraction or use, other activities that previously could not use the formally expensive resource can now be supplied more cheaply, thus increasing demand. Third, given the impact of lessening reserves for future generations, the only responsible course was to ensure that current activities generated the maximum long-term benefit with minimal waste. Jevons identified poverty reduction, education, improved housing and (for the UK) national debt reduction as the responsible goals his generation should attain if it was to be well regarded by later generations. While his views differ slightly from current views of what constitutes weak sustainability, Jevons did directly consider the issue of intergenerational equity and the need for his generation to act responsibly. While many might think that economics today is exclusively focussed with contemporary financial affairs, numerous economists have tackled problems of long-term environmental concern, including questions of sustainable growth paths and the depletion of both renewable and nonrenewable resources.[4]

In the past century, economists who have focussed on economic growth have mostly attempted to explain the massive change in living standards that has occurred over the past 200 years and the factors that have advanced some nations ahead of others (Clark, 2014; Jones, 2015; Maddison, 1998). The avoidance of Malthusian traps has meant this literature has not focussed on environmental constraints to long-term growth, although there is a recognition that continued technological improvement and external energy are required to sustain growth beyond the steady-state (Brock & Taylor, 2004). While some economists have examined the interaction between markets, prices and resources in the short term, others have considered inter-generational issues (Gaudet, 2007; Krautkraemer, 1998). Hotelling (1931), for example, formally addressed the issue of inter-temporal efficiency and exhaustible resources, establishing some of the best known rules for efficient (as opposed to wasteful) extraction.[5] Robert Solow (1974a, 1974b) and Markandya and Pearce (1991), among many others, have examined how we might evaluate our current use of resources against leaving those same resources for future generations.[6] Most importantly, they have attempted to evaluate the true costs of sacrificing consumption today to allow for consumption tomorrow. Since the mid-1970s when the Club of Rome argued that economic development and environmental quality were incompatible, much work has been achieved in establishing economic objectives consistent with environmental sustainability (Meadows, D. H., Meadows, D. L., Randers, & Behrens, 1972). Nonetheless, while the mathematical estimations of costs and benefits are relatively straightforward, it is also clear that the moral and ethical considerations to help inform this choice lie outside a purely economic solution (Damon & Sterner, 2012).

Overcoming Market Imperfections – Economic Techniques to Transition to a Circular Economy

At these levels of abstraction then, there is little contradiction between the aims of the circular economy '…an economy that provides multiple value-creation mechanisms which are decoupled from the consumption of finite resources…' and the problems faced in economics (Ellen MacArthur Foundation, 2015, p. 23). From an economic perspective, what is critical for transitioning to a circular economy is that everyone has full information about the relative costs of the resources consumed and goods produced and the alternative choices that are foregone. The economic perspective on the problem of transition, therefore, focusses on how individuals, firms and countries perceive the costs of their actions and decisions, and how their incentives can be aligned with the objective of cradle-to-cradle production and consumption processes. The argument here is not that economics offers the only solution to the transition to a circular economy, but rather, that economic solutions cannot be overlooked as one of the important mechanisms by which individual and social behaviour can be adjusted at minimal cost and maximum benefit. This approach is also consistent with the view that government regulation, however well intentioned, cannot guarantee a smooth and minimal cost transition to a circular economy; changes to individual behaviour, not just government decree, are required.

Some will immediately object that this approach is simply a form of monetisation of the environment, an idea that has been discussed many times before (Baveye, Baveye & Gowd, 2013; Laurre, 1995). Such an objection, however, misses the point that for the circular economy to become imbedded as standard practice, transition processes will be required that facilitate both individuals, firms and communities to change from simple linear production models to circular processes. Such a change cannot simply be imposed from above, nor can the capacities and inventiveness of humans to develop this system be advanced without the opportunity for individual responses. Market signals facilitate such responses.

It is clearly impossible for everyone to have comprehensive knowledge of the complete relative costs and benefits of all resources and their alternative uses. The power of the market, however, is that price serves as a signal to communicate these costs and benefits in a single, immediately comparable way. The potential universality of this mechanism, its flexibility to respond to supply and demand changes, its immediacy and its ability to transcend language barriers makes the invention of the price mechanism one of the most important in human history. Like all human inventions, however, it also contains flaws. The central issue is, can the price signals that are used in markets be an accurate reflection of the true costs and benefits of resource consumption and material production?

While competitive markets can deliver accurate price signals under certain specific, but mostly unrealised preconditions, it has long been known that many resources and outputs do not have 'accurate' (scarcity reflecting and demand signalling) prices.[7] There can be any number of reasons for this, most of which involve some violation of the conditions for full (if not perfect) competition. Given the potential communicative power of prices, however, much effort has been given to overcome these shortcomings.

For example, markets fail when goods or resources exist 'outside' the market and where outputs impact on people outside that market. These effects are called externalities'. The most common negative externalities, different forms of pollution, exist in this framework because either the producer does not bear the true cost of production (which includes the negative impacts of their pollution) or others are not willing or able to pay to reduce the pollution. In each case, however, so long as there is net social benefit to be derived from the activity, there will be some level of pollution actually produced.[8] Where negative externalities (like CO_2) are under-priced and overproduced, one solution is the imposition of a tax, which raises the cost of production and reduces the amount produced to optimal levels (Pigou, 1920). Another solution may be to create a market (as with tradable permits for CO_2) and allow firms to trade these (thus also pricing CO_2). Where the ownership of the resources is clear (unlike, the situation with atmospheric pollution), and the individuals involved not overly numerous, negotiation and contract can also be used to ensure damage (if done) is either compensated or prevented (Coase, 1960). A third option is through government regulation; for example, requiring those who benefit from the activity to bear the full cost of the externality.[9] In all these cases, the previous externality is, in some way, brought inside the market, and the tools of the market used to determine the quantity produced. The weakness of these possible solutions is also well known, including the need for information about the true social cost of the externality. This has not stopped many of these mechanisms from being introduced with a positive impact.[10]

Markets also fail where the goods or resources involved can be consumed by more than one individual at the same time, and it is difficult (or impossible) to charge users for access to the goods. These public goods are frequently provided collectively (through government). However, in the case of resources, the lack of clear responsibility for sustainability may become the result. This problem, often cited as 'the tragedy of the commons', is applied to many common access resources where individuals pursuing their own interests may degrade and sometimes destroy the resource (Hardin, 1968).[11] Economic-based solutions to this problem range widely: from privatisation of the resource as one solution, to achieving a deeper understanding and awareness of common responsibilities, behaviours and social repercussions for infringement (Ostrom, 2010).

Perhaps more challenging are the claims of future generations, and how these can be signalled in a market. Consider the following definitions of the circular economy and sustainability. The circular economy is 'A regenerative system in which resource input and waste emission and energy leakage are minimised by slowing, closing and narrowing material and energy loops…' achieved '…through long lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling'. Sustainability, on the other hand, is '… the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations' (Geissdoerfer et al., 2017, p. 766). Together these perspectives require that current market prices include a factor that values the needs of future generations. Even when the need to include a 'discount rate' for consumption into the future is recognised, however, there is little agreement on the specific values to use.[12] Markets will continue to fail to price current consumption correctly until an 'agreed value' of future interests is reached; something that will require consideration of issues outside the market place alone.

Yet another element that must be overcome for market instruments to signal correctly the relative scarcity and value of resources is that of market power by producers. Where firms are able to set their product's price and quantity, or dominate resources markets, rather than be subject to competitive pressures, prices no longer serve as an accurate signal of goods' relative costs or benefits. While many of the world's resource and commodity markets are currently controlled by non-competitive industries, it is important to realise that this is not an inevitable outcome. Regulatory frameworks that prohibit such structures and require increased competition, and thus accurate prices, are possible (Fellman & Shanahan, 2016).

The use of 'full' (socially and environmentally accurate) prices in the production and consumption of goods and services would significantly assist in the transition to a circular economy. Increases in the relative price of environmentally scarce resources would quickly trigger changes in consumer behaviour (to be less wasteful and seek alternatives) while also signalling to suppliers the value of these resources, so encouraging them to seek alternatives, substitutes or (where feasible) re-growing or re-establishing a renewable resource.

Accurate prices by themselves, will not, however, guarantee sustainability. Just as high prices might signal to consumers to conserve their use of an expensive resource and to entrepreneurs to invent alternatives or to reuse and recycle components, it will also provide incentives to others to plunder scarce, but unprotected sources. Market mechanisms, to work correctly, must be buttressed and supported by consistent and enforced laws, appropriate institutions and individual and social attitudes. While markets can be modified to respond to issues of externalities, the supply of public goods, or cartels and monopolies, less optimistic researchers have suggested that any such solutions produced via economic instruments will only go part-way to creating sustainability. To achieve a truly circular economy, one that works in line with natural limits by mimicking natural cycles of use and reuse, also requires a transformation in human thinking.

It is here that the ideas of Nobel Prize-winning economist, Douglass North (1981, 1990) has something to contribute. The 'mental constraints' through which individuals see the world are consistently modified by, and modify, the institutions within which they work.

> History demonstrates that ideas, ideologies, myths, dogmas, and prejudices matter; and an understanding of the way they evolve is necessary for further progress in developing a framework to understand societal change. .... Belief structures get transformed into societal and economic structures by institutions – both formal rules and informal norms of behavior. (North, 1994, pp. 362–363)

This suggests that in addition to adapting market mechanisms to signal the value inherent in recycling and reusing, the idea of the circular economy, and the principles it embodies, must also be more broadly understood and accepted.

North suggests there are five elements crucial in explaining institutional change:

1. The continuous interaction between institutions and organisations in the economic setting of scarcity, and hence competition is the source of institutional change.
2. Competition forces organisations to continually invest in skills and knowledge to survive. The kinds of skills and knowledge individuals and their organisations acquire will shape evolving perceptions about opportunities and hence choices that will incrementally alter institutions.
3. The institutional framework provides the incentives that dictate the kinds of skills and knowledge perceived to have the maximum pay-off.
4. Perceptions are derived from mental constructs of the players.
5. The economics of scope, complementarities and network externalities of an institutional matrix make institutional change overwhelmingly incremental and path dependent (North, 1993, p. 17).

This interpretation of how institutions and societies change, if correct, further supports the argument that market mechanisms must be part of the path dependent transition to a circular economy.

One historical example of a change in economic attitudes, which is also of direct relevance to the circular economy, might help illustrate this process. In response to the Great Depression in the 1930s, the notion of planned obsolesce was suggested as a means by which to raise living standards and ensure employment and economic growth. The idea took hold in many parts of the western world beginning from the 1940s to 1960s (London, 1932; Packard, 1960). This approach to production and consumption aligned powerfully with economic incentives, and helped expand the world-wide adoption of the 'straight line' economy. Although the acceptance of this change in attitudes took several decades, it did result in a change to social mores about what were acceptable and 'standard' consumption and production processes (Andrews, 2015). If planned obsolesce can become accepted as 'standard practice', so too can ideas and attitudes consistent with a circular economy. The anxiety, of course, is that to alter individuals' perceptions in favour of a 'cradle-to-cradle' production and consumption process, may require an environmental catastrophe on parallel with the economic disaster that was the 1930s depression. A more optimistic view, however, would be that humans are able to transition to a circular economy without the need for such an environmental disaster.

While governance and institutional factors would need to align with the circular economy's values and processes, another attitudinal change might be the broader adoption of the precautionary principle when evaluating projects and change. The precautionary principle states that 'When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm' (COMEST, 2005, p. 14). Such a principle could be made a fundamental requirement of project planning, in the same way other legal requirements of contract enforcement or property rights are currently required. The impediment to change is not that it could not be done, but that it will be costly to implement and does not align with current practice and self-interest. The required change is not to economic tools *per se*, but to existing attitudes, incentives and price signals. This will take political leadership at every level of government, as well as a change in attitudes towards our relationship with future generations and the legacy we wish to leave them.

Changing Behaviour and Changing Incentives

Modifying human behaviour, adjusting individual and community incentives and signalling the relative value of resources are all things well suited to influence by economic instruments. An obvious, but often forgotten fact is that markets, prices, the rules for valuing resources or deciding on choices – are all human-made institutions. Shifting individual and community perspectives from linear, short-term processes to circular, long-term processes should not be beyond our capacity as rational, logical beings, but neither will it be simple to achieve.

To use economics to transition to a circular economy, therefore, necessarily requires a combination of economic instruments, institutions and ideological change. Professor Elinor Ostrom won the Nobel Prize for Economics in 2009 for her analysis of social organisation and its impact on complex environmental problems. Her work is of direct relevance to the problem of how we transition to a more circular economy, and it suggests that economic insights have much to offer in assisting in that process.

> The most important lesson for public policy analysis … is that humans have a more complex motivational structure and more capability to solve social dilemmas than posited in earlier rational-choice theory. Designing institutions to force (or nudge) entirely self-interested individuals to achieve better outcomes has been the major goal posited by policy analysts for governments to accomplish for much of the past half century. Extensive empirical research leads me to argue that instead, a core goal of public policy should be to facilitate the development of institutions that bring out the best in humans. We need to ask how diverse polycentric institutions help or hinder the innovativeness, learning, adapting, trustworthiness, levels of cooperation of participants, and the achievement of more effective, equitable, and sustainable outcomes at multiple scales. (Ostrom, 2010, 664–665)

Thus, while simple markets mechanisms, when properly designed and accurate in their pricing signals can be used to send information about the relative value of resources, and the opportunity cost of choosing between alternative uses, other, institutional and social changes must also be in place to facilitate the transition to a circular economy. Some work has begun in this space. Walter Stahel's proposals for the substitution of human labour for energy and the purchasing of goods' services, rather than the goods themselves, are examples of how questions of production and conception may be framed differently to advance a more circular flow of resources, while still utilizing market mechanisms to allocate resources (Stahel, 2010, 2016).

Just as such proposals reframe our perspective on what it means to 'make' something – so too our frame of reference on the purpose behind using economics as a tool for decision-making and resource allocation needs to be revisited. In 1848, John Stuart Mill (2001, p. 188) asked, 'Towards what ultimate end is society tending by its industrial progress?'

Amaryta Sen's view, that resources should be allocated to enhance human capabilities, is consistent with a philosophical shift that moves the values underlying the market mechanism away from simply material production maximisation and nudges it towards individual growth and capacity building (Sen, 1970, 1985). As with Stahel's work, it opens up consideration of processes that *could* shift resource flows from the linear to the circular.

As with any human invention, however, there must be a willingness to make change, as well as the possibility.

Conclusion

Conceptualizing earth as a 'space-ship' that enables us to survive in a hostile universe was a powerful image that reframed the debate about resource use and the urgency of sustainable, rather than just maximum, development. Like few other images, this view reminded us of the scarcity of our inhabitable environment, and the need to make sensible and long-term choices within that constraint.

The transition to a circular economy will require many changes and economic ideas and instruments are one important component that can be used to assist in that process of change. Exactly how disruptive that change may prove to be is still unclear. Humans have a great capacity for change and adaptation. The race to create a circular economy and so improve our ability to produce an environment in which we can sustain both ourselves and our planet is still being run.

Notes

1. The carbon cycle describes the overall closed loop through which carbon atoms move, through atmosphere, oceans and living organisms sustaining life and being reused over time.
2. Although there are some partial exceptions (Andersen, 2007; Bechtel, Bojko, & Völkel, 2013; Berndtsson, 2015; Ghisellini, Cialani, & Ulgiati, 2016; Persson, 2015).
3. Laurre (1995) reaches a similar conclusion, albeit from the opposite perspective.
4. For an introduction see Turner, Pearce, and Bateman (1994, pp. 1–11) and Pearce (2002).
5. He was careful to note that a different set of problems was posed by a renewable resource which 'which may replenish itself if not too rapidly exploited' (1931, p. 140).
6. For a more recent application examining climate change and the costs of addressing this, see Stern (2006, Chapter 2).

7. The standard list of requirements for a theoretically perfectly competitive market (in addition to assumed institutional and behavioural assumptions) include well-defined property rights, individual consumers and suppliers with perfect information unable to influence price and who make rational decisions, homogenous inputs and outputs product, accessible entry and exit from markets, no increasing returns to scale and no externalities or transaction costs. Importantly, in such markets, goods must also generally be 'private' rather than 'public' in consumption. As with the 'perfect vacuum' in physics, the perfectly competitive market state does not actually exist. Its usefulness lies in theoretical comparisons as a hypothetical benchmark from which real markets can be examined.
8. Clearly, there are some products or externalities whose social cost is so high that the benefits of production will never match the costs – and so they should not be produced at all.
9. Extended Producer Responsibility for waste packaging in the European Union is a move in this direction. More complete examples include, requiring river polluting factories to place their waste outlet pipes upstream from their water inlet pipes, or requiring all vehicle exhaust pipes to vent into the driver's cabin.
10. In recent years, the European Union has made significant efforts to quantify the true cost of many forms of pollution, and move towards pricing them correctly.
11. Examples include, overfishing, forestry exploitation and water extraction.
12. For a recent example, see the debates between Stern and Nordhaus over the appropriate future discount rates needed to properly price efforts to mitigate climate change in a sustainable manner (Goulder & Williams, 2012; Nordhaus, 2007; Stern, 2007).

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Chapter 3

China's Policies for Promoting the Circular Economy: Past-Decade Experiences, Future Plans and Success Stories

Xu Zhao

Abstract

Smog and other environmental effects of accelerated industrialisation are increasingly driving China towards more restorative economic models. One of these is the circular economy (CE), which encourages the design of products and systems that can be returned and the materials recycled, reused or remanufactured. This chapter discusses the experiences with China's policies for promoting the CE over the past decade as well as future plans. It is based on a thorough review of China's policies originally available in Chinese. Exemplary CE projects with success stories are also presented. The aim is to present a more comprehensive understanding of China's CE efforts. Other developing countries also facing environmental and resource challenges can draw on China's experiences in developing their own CE.

Keywords: Circular economy; recycling; resource efficiency; environmental policy; sustainability; China

Introduction

The circular economy (CE) concept was first proposed by two British environmental economists Pearce and Turner (1990). By transforming traditional 'resources-products-pollutions' mode into 'resources-products-regenerated resources' mode, namely turning wastes at one point in a value chain into inputs at another point, CE could realise a closed loop of resource and energy flows in economic systems (Mathews & Tan, 2011). The implementation of CE has obtained great success in developed countries, such as the United States, Japan and

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doi:10.1108/978-1-78714-619-820181006

Germany (Moriguchi, 2007), in preventing further environmental deterioration and conserving scarce resources through effective waste management, especially integrated solid waste management.

In China, CE has seen three development stages in less than 20 years. Between 1998 and 2000, the concept was first introduced and theoretically studied in higher education institutions. The second stage from 2001 to 2005 saw the advent of clean production in enterprises and eco-industrial parks. But since 2006, China, having been facing increasingly serious resource challenges and environmental threats, has adopted CE as a new development model rather than just an incrementally improved environment management policy, which helps China leapfrog into a more sustainable economic structure (Geng & Doberstein, 2008; Zhu, 2008, 2014). In China, the main focus of CE's original concept has gradually been shifted from a narrow perspective of only waste recycling to more broad efficiency-oriented control during the closed-loop flows of materials at all stages of production, distribution and consumption. Moreover, energy efficiency and conservation, land management and soil protection, and integrated water resource management problems have also been considered as key issues, aside from resources and waste problems.

For the first time, the development of CE was officially called for as a major strategic task in China's 11th Five-Year plan (2006–2010) National Economic and Social Development Plan (NDRC, 2006a), which also first set quantitative and compulsory targets in resource conservation and pollution control (specifically 20% decrease for energy consumption per unit of GDP, 30% decrease for water consumption per unit of industry value added and 10% reduction in total discharge of major pollutants such as SO_2 and COD). The corresponding targets in the ensuing 12th Five-Year Plan (2011–2015) were 16%, 30% and 8%, respectively (NDRC, 2011b). In and around both the 11th and 12th Five-Year plans (which spans a decade: 2006–2015) and with a top-down approach, China deployed an array of effective policies and measures for developing CE tailored to Chinese characteristics, and achieved significant progress in resource conservation and pollution control (refer to Figs. 3.1 and 3.2 and Table 3.1).

Based on a thorough review of China's policies originally available in Chinese, this chapter introduces the experiences of China's policies for promoting CE over the past decade as well as future plans. Exemplary CE projects are also presented in success stories. The aim is to present a more comprehensive understanding of China's CE efforts in order that other developing countries also facing environmental and resource challenges can draw on China's experiences in developing their own CE.

Past-Decade Experiences

Fig. 3.3 presents the temporal development of policy issuance. It can be seen that China began to deploy a significant number of CE policies and measures from 2005, and accordingly, CE indicators, for example, energy consumption per unit of GDP, have been decreasing from 2006 on. Based on the impact and effectiveness, Table 3.2 presents the key policies and measures among those ever deployed by China from 2005 to 2016.

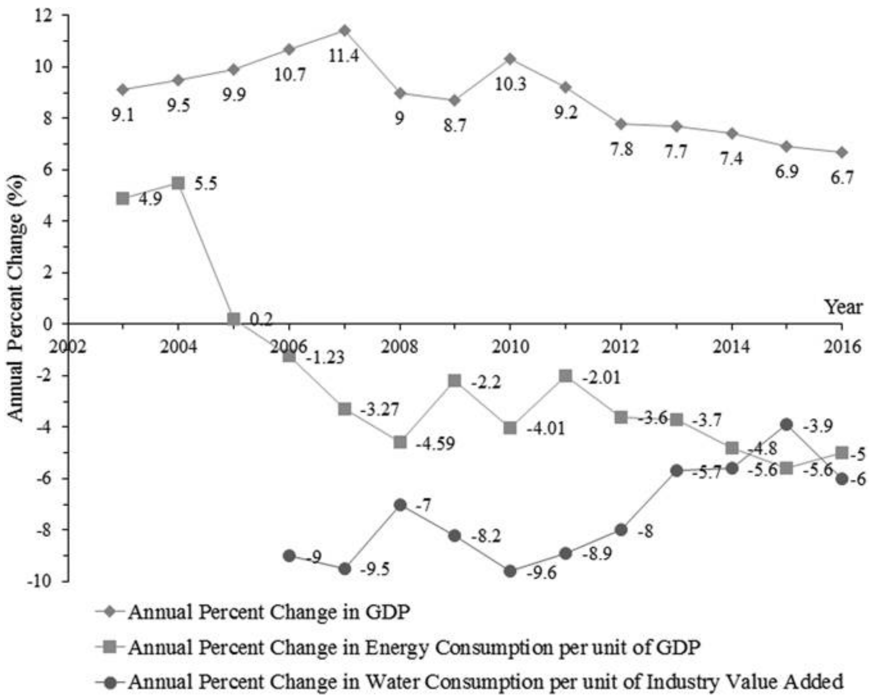

Fig. 3.1: Annual Percent Change (APC) in GDP Versus APC in Major Resource Consumption Indicators for Mainland China. *Sources*: NBS (2003–2015) and NPC (2004–2017).

'Several Opinions of the State Council on Accelerating the Development of CE'

On 2 July 2005, State Council issued 'Several Opinions of the State Council on Accelerating the Development of Circular Economy' (SC, 2005). This was the first national-level guiding document on developing CE in China, marking CE development as a national strategy and heralding the 'top-down' CE development practice. The document first acknowledged the serious resource and environment pressures China would face during its accelerated industrialisation and urbanisation stage (2000–2020), and called for a vigorous development of CE according to the principle of '3Rs' ('Reduce, Reuse and Recycle') and 'Reduce First', so that a unity of economic, environmental and social benefits can be achieved in building a resource-saving and environmentally friendly society.

To this end, the document specifically put forward the following opinions (i) guiding ideology, basic principles and main objectives for the development of CE; (ii) the focus of work and key aspects in developing CE; (iii) strengthening the macro guidance on the development of CE; (iv) accelerating CE R&D and the construction of a standard system; (v) establishing and improving the policy

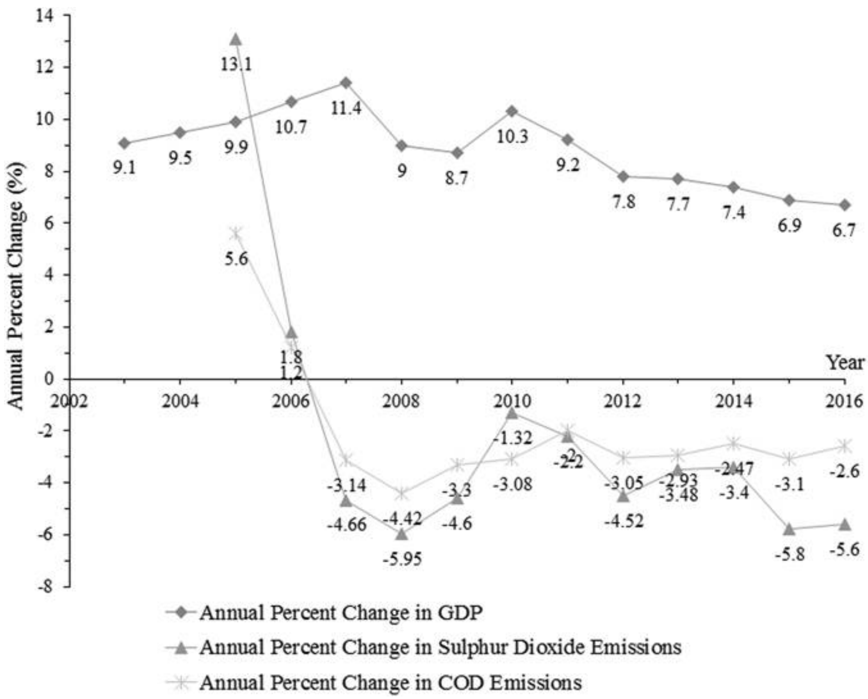

Fig. 3.2: Annual Percent Change (APC) in GDP Versus APC in Major Pollutant Emission Indicators for Mainland China. *Sources:* NBS (2003–2015) and NPC (2004–2017).

Table 3.1: Values of GDP, Major Resource Consumption and Pollutant Emission Indicators in Year 2005 (To Give a Sense of the Absolute Values of Indicators Shown in Figs. 3.1 and 3.2).

Year	**GDP**	**Energy Consumption Per Unit of GDP**	**Water Consumption Per Unit of Industry Value Added**	**SO_2 Emission Total**	**COD Emission Total**
2005	18.2 trillion CNY	1.22 tons of standard coal per 10,000 CNY	169 cubic metres per 10,000 CNY	25.49 million tons	14.14 million tons

Sources: SC (2007) and NDRC (2006b).

mechanism to promote the development of CE; (vi) adhering to law in promoting the development of CE; and (vii) strengthening the organisation and leadership on the development of CE.

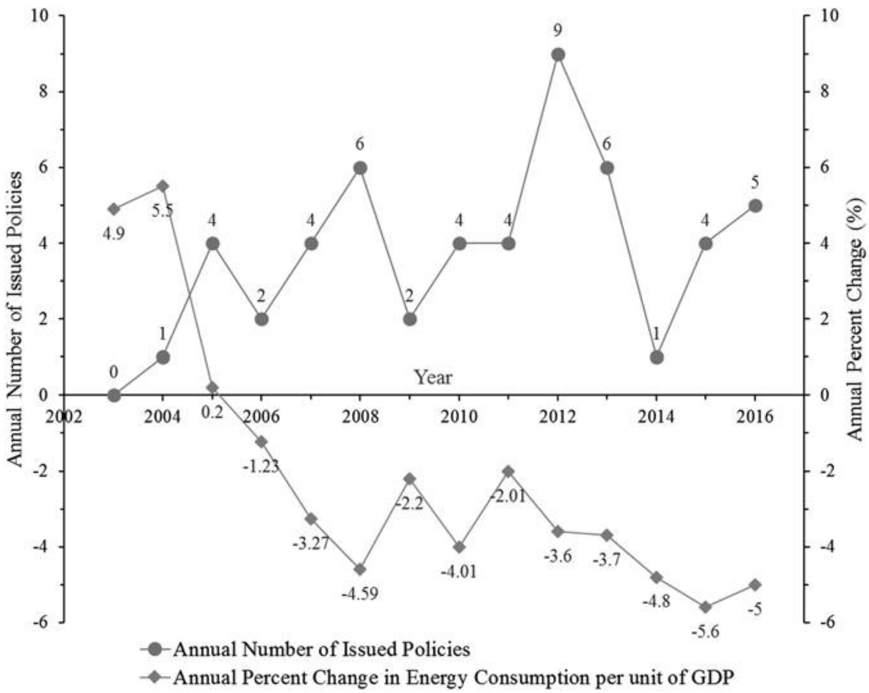

Fig. 3.3: Annual Number of Issued Policies Versus APC in Energy Consumption Per Unit of GDP. *Source of policy number*: NDRC (n.d.), RCEP (n.d.) and SC (n.d.).

Organizing CE Pilot Projects

The overall objectives of organizing CE pilot projects are (i) to explore the development mode of CE in key industries including iron and steel, nonferrous metals, coal, power generation, chemical industry, building materials, light industry, etc., and establish a number of typical CE enterprises; (ii) to establish resource recycling mechanisms in key areas such as renewable resource recycling systems, scrap metal recycling, waste household appliances recycling and remanufacturing, etc.; (iii) to put forward CE-based planning, construction, transformation of development zones and industrial parks to form a number of CE industry demonstration parks; and (iv) to explore the development mode of CE in the city and form a number of CE demonstration cities (NDRC, 2005).

Inter-Ministerial Joint Conference System

To strengthen the organisation and leadership in the development of CE and enhance coordination between government departments, the State Council approved the establishment of an Inter-Ministerial Joint Conference system for CE development (SC, 2006).

Table 3.2: Key Policies and Measures for Developing CE in China from 2005 to 2016.

No.	Issuance Date	Title	Issued by
1	2 July 2005	Several opinions of the State Council on accelerating the development of CE	SC
2	27 October 2005	Notice on the organisation of CE pilot projects (the first batch)	NDRC, MEP, MOST, MOF, MOC, NBS
3	27 January 2006	Approval on the establishment of an Inter-Ministerial Joint Conference system for developing CE	SC
4	27 June 2007	Notice on the issuance of CE Evaluation Indicator System	NDRC, MEP, NBS
5	29 August 2008	CE promotion law	NPC
6	19 April 2010	Opinions on investment and financing policy measures for the development of CE	NDRC, PBC, CBRC, CSRC
7	29 June 2011	Notice on the construction of national demonstration base for CE education	NDRC, MOE, MOF, NTA
8	20 July 2012	Notice on interim measures for the administration of special funds for the development of CE	MOF, NDRC
9	23 January 2013	Notice on strategy and action plan for the development of CE in the near future	SC
10	4 May 2016	Notice on the distribution of typical experience from national CE pilot projects	NDRC, MOF
11	27 December 2016	Notice on the issuance of CE Development Evaluation Indicator System (2017 Edition)	NDRC, MOF, MEP, NBS

Notes: The acronyms shown in the column of 'Issued by' stand for various Chinese governmental departments such as State Council (SC), National Development and Reform Commission (NDRC), Ministry of Environmental Protection (MEP), Ministry of Science and Technology (MOST), Ministry of Finance (MOF), Ministry of Commerce (MOC), National Bureau of Statistics (NBS), National People's Congress (NPC), National Tourism Administration (NTA), The People's Bank of China (PBC), China Banking Regulatory Commission (CBRC) and China Securities Regulatory Commission (CSRC).

The main responsibilities of the Inter-Ministerial Joint Conference system are (i) to study and formulate key policies and benchmarks for CE development and make recommendations to State Council; (ii) to coordinate on and solve major problems in the development of CE; (iii) to determine key annual works and coordinate their implementation; and (iv) to provide guidance, supervision and inspection for the development of CE.

The Inter-ministerial Joint Conference system consists of deputy ministers/directors from the National Development and Reform Commission (NDRC), Ministry of Environmental Protection (MEP), Ministry of Science and Technology (MOST), Ministry of Finance (MOF), Ministry of Land and Resources (MOLR), Ministry of Housing and Urban-Rural Development (MOHURD), Ministry of Water Resources (MWR), Ministry of Agriculture (MOA), Ministry of Commerce (MOC), State-owned Assets Supervision and Administration Commission (SASAC), State Administration of Taxation (SAT), National Bureau of Statistics (NBS) and State Forestry Administration (SFA). The ministers/directors hold a regular meeting every year.

CE Evaluation Indicator System

To implement the 'Opinions on accelerating the development of CE' (SC, 2005), scientifically evaluate CE development in the nation and provide data support for the formulation and implementation of CE development planning, NDRC, MEP and NBS jointly developed a CE Evaluation Indicator System in 2007 (NDRC, 2007). The CE Evaluation Indicator System makes full use of the existing data in accordance with the basic characteristics of CE, and comprises the macro level and the industry park level (Table 3.3).

From 2007 to 2016, with the continuous deepening and expanding of CE practice in China, especially after the 18th CPC National Congress placed green circular and low-carbon development as the basic path of constructing ecological civilisation, it became necessary to revise the CE Evaluation Indicator System (2007 edition) according to the latest requirements of ecological civilisation construction and the realistic needs of developing CE. Hence, a revised CE Development Evaluation Indicator System (Table 3.4) was put forward and entered into force on 1 January 2017 (NDRC, 2016c). The 2017 edition indicator system improves the specific evaluation indicators and clarifies the specific statistical and measurement methods.

CE Promotion Law

The CE Promotion Law was passed at the 4th meeting of the Standing Committee of the 11th National People's Congress of the People's Republic of China on 29 August 2008. It entered into force as of 1 January 2009.

CE Promotion Law has a legal framework designed in accordance with the order of implementing 'reduce, reuse, recycle', which is also adopted as the main approach to solving problems in the development of CE (NPC, 2008). To sum up, the guiding ideology of the CE promotion law is mainly reflected in the following

Table 3.3: China's CE Evaluation Indicator System (effective until 31 December 2016).

	Indicators (Macro)	Indicators (Industry Parks)
1. Resource output	Output rate of main mineral resources Output rate of energy	Output rate of main mineral resources Output rate of energy Output rate of land Output rate of water
2. Resource consumption	Energy consumption per unit of GDP Energy consumption per unit of industry value added Comprehensive energy consumption of main products in key industries Water consumption per unit of GDP Water consumption per unit of industry value added Water consumption of per unit of products in key industries Effective utilisation coefficient of agricultural irrigation water	Energy consumption per unit of GDP Water consumption per unit of GDP Energy consumption per unit of key products Water consumption per unit of key products
3. Comprehensive utilisation of resources	Comprehensive utilisation rate of industrial solid waste Reuse ratio of industrial water Recycling rate of municipal wastewater Harmless treatment rate of municipal solid waste Recycling rate of scrap iron and steel Recycling rate of waste nonferrous metals Recycling rate of waste paper Recycling rate of waste plastics Recycling rate of waste rubber	Comprehensive utilisation rate of industrial solid waste Reuse ratio of industrial water
4. Waste discharge	Industrial solid waste disposal Industrial wastewater discharge amount Sulphur dioxide emissions COD emissions	Industrial solid waste disposal Industrial wastewater discharge amount Sulphur dioxide emissions COD emissions

Table 3.4: China's CE Development Evaluation Indicator System (2017 Edition).

Types	**Indicators**	**Units**
Comprehensive indicators	Output rate of major resources	CNY per ton
	Main waste recycling rate	%
Specific indicators	Output rate of energy	10,000 CNY per ton of standard coal
	Output rate of water	CNY per ton
	Output rate of land for construction	10,000 CNY per hectare
	Comprehensive utilisation rate of crop straw	%
	Comprehensive utilisation rate of general industrial solid waste	%
	Water reuse rate by enterprises above designated size	%
	Recycling rate of major renewable resources	%
	Resourcification utilisation rate of municipal food waste	%
	Resourcification utilisation rate of urban construction waste	%
	Utilisation rate of municipal recycled water	%
	Resource recycling industry output value	100 million CNY
Indicators for reference	Industrial solid waste disposal amount	100 million tons
	Industrial wastewater discharge amount	100 million tons
	Municipal solid waste landfill amount	100 million tons
	Emissions of key pollutants (calculated respectively)	10,000 tons

principles: (i) 'Reduce First'. The CE in western developed countries has generally focussed on waste recycling, while China, facing a serious waste of energy and resources in its stage of rapid development of industrialisation, pays great attention to the potential of 'reduce'; (ii) focussing on key industries and key enterprises with high-energy consumption and heavy pollution; (iii) placing strict constraints on high-consumption and high-emission behaviours, while providing a series of incentive policies for enterprises to develop the CE; (iv) promoting concerted efforts among government, enterprises, the public and industry associations in production, circulation and consumption.

Specifically, the CE Promotion Law established the following systems/measures: (i) a CE planning system; (ii) a total amount control system to restrain the waste of resources and pollutant emission; (iii) a system of extended responsibility for producers; (iv) a supervision and management system for high-energy consumption and high-water consumption enterprises; (v) strengthened role and guidance of industry policies; (vi) the specific requirements of 'Reduce'; (vii) the specific requirements of 'Reuse and Recycle'; (viii) incentive mechanisms through fiscal measures; and (ix) the system of legal liability.

Investment and Financing Policy Measures

To implement the CE Promotion Law, the State Council's 'Opinions on accelerating the development of CE', increase investment and financing policy support for the development of large-scale CE, NDRC, The People's Bank of China (PBC), China Banking Regulatory Commission (CBRC) and China Securities Regulatory Commission (CSRC) jointly put forward the following: (i) highlighting the importance of investment and financing policy support for the development of CE; (ii) giving full play to the guiding role of government planning, investment, industry and price policies; (iii) enhancing the overall financial services through focussed credit support and innovative financial products; (iv) developing direct financing multichannels including debt financing, equity investment funds, venture capital enterprises and IPO; (v) promoting the use of foreign funds such as international financial organisation loans, foreign government loans and Clean Development Mechanism (CDM); and (vi) strengthening coordination to achieve the effective implementation of relevant policies (NDRC, 2010).

National Demonstration Bases for CE Education

To implement CE Promotion Law and promote scientific knowledge on CE among the public, NDRC, MOE, MOF and NTA initiated the construction of national demonstration bases for CE education in 2011 (NDRC, 2011a). The initiative aimed to build CE promotion platforms and education and training bases, promote typical CE models and guide the public to participate in CE development.

During the period of the 12th Five-Year Plan (2011–2015), the initiative constructed a number of national demonstration bases for CE education featuring advanced technology, leading management and strong CE characteristics. The scope of this detailed work included building CE education and exhibition venues and facilities, producing CE education films, setting up dedicated access routes for visitors, security facilities, necessary means of transport and professional staff. According to visits by students and the public, such a base can provide dedicated types of education and related activities.

To be recognised as a candidate for the scheme, the base had to meet the following criteria: (i) listed as a national CE (including remanufacturing) pilot project or provincial CE pilot from national CE pilot provinces; (ii) featuring evident CE characteristics with a relatively complete industry chain; (iii) having certain education, visitor and display facilities, security measures and relatively fixed opening hours for the public, especially for primary and secondary school students; (iv) situated close to large and medium cities, or densely populated areas with convenient transportation and no less than 1,000 visitors of various types in 2010; (v) having good social standing and no illegal records within the previous 5 years. NDRC, MOE, MOF and NTA also released a logo design for dedicated national demonstration bases for CE education (Fig. 3.4).

Special Fund for CE Development

To regulate the management of special funds for CE development, improve efficiency in the use of fiscal funds, according to China's CE Promotion Law & Budget Law, etc., MOF and NDRC jointly formulated the 'interim measures for the administration of a special fund for the development of CE' in 2012. The special fund for CE development refers to fiscal funds arranged by the central government budget and earmarked for the implementation of key CE projects, CE technology and product demonstration and promotion and CE capacity building. The fund is managed by MOF in conjunction with other CE-managing departments in accordance with the division of duties and responsibilities.

The use and arrangement of the fund adheres to the following principles: (i) giving full play to the fundamental role of markets while following government guidance; (ii) employing innovative fiscal measures; (iii) concentrating financial resources on key breakthroughs; (iv) adhering to the principle of being 'scientific, open and fair'; and (v) accepting supervision from the society.

The special fund supports the following types of key work in scope: (i) construction of national 'minerals from cities' demonstration bases; (ii) utilisation

Fig. 3.4: Logo of National Demonstration Bases for CE Education.

and environmentally friendly disposal of kitchen waste; (iii) industry park circular transformation and demonstration; (iv) remanufacturing; (v) demonstration and promotion of clean production technologies; (vi) capacity building in CE and clean production; and (vii) other key projects determined by MOF and other CE-managing departments.

The special fund takes different approaches to support various types of key CE projects: (i) the fund adopts a combination of preallocation and clearing in providing financial assistance for the first three types on the above list; (ii) with respect to remanufacturing, the fund provides a subsidy for old part collection and the promotion of remanufactured products provided that there exists a quality assurance system; (iii) for mature, advanced and applicable clean production technologies identified by expert advice, the government uses the special fund for their purchase and promotes them in the industry; and (iv) funding assistance for CE capacity building is included in the relevant department's budget in accordance with provisions on budget management.

Strategy and Action Plan for CE Development in the Near Future

To guide and accelerate CE development to fulfil the '12th Five-Year (2011–2015) Plan' goal of an increasing resource output rate by 15%, the State Council issued 'strategy and action plan for the development of CE in the near future' (hereinafter referred to as 'strategy and action plan') in January 2013 (SC, 2013). This was China's first national strategic plan for CE development.

This 'strategy and action plan' revolved around the overall requirements for constructing ecological civilisation, improving energy and resource utilisation efficiency and enhancing the quality of the environment. In accordance with the principle of 'Reduce, Reuse, Recycle' and 'Reduce First', the 'strategy and action plan' provided specific targets on resource output rates, land output rates, water output rates, etc., put forward concrete policies and measures for developing CE in production, circulation and consumption, and made specific arrangements for their deployment in various industries, fields and throughout China.

The strategy and action plan put forward four key tasks: (i) to build a circular industrial system; (ii) to build a circular agriculture system; (iii) to build a circular service system; and (iv) to promote CE development at the social level.

The strategy and action plan also proposed the 'ten, hundred & thousand' demonstration initiative, that is, implementing 10 CE demonstration projects, constructing 100 CE demonstration cities (counties) and fostering 1,000 CE demonstration enterprises/parks (Fig. 3.5).

Typical Experience from National CE Pilot Projects

NDRC, MOF and other relevant departments carried out a midterm assessment of key areas of CE development work, analysed the exploration and practice of national CE pilot projects, and summarised a number of useful typical experiences, mechanisms and models to be promoted, including: (i) a collaborative CE

Fig. 3.5: Logo of National Demonstration Pilot Park of Cyclic Transformation.

promotion mechanism centred on strengthening local legislation and improving supporting policies; (ii) an industrial park circular development mechanism with investment chain supplementing and risk sharing at its core; (iii) a waste resource management mechanism with a waste flow reporting system and public information service platform at its core; (iv) an industrial waste third-party service mechanism with embedded management and overall solutions at its core; (v) an urban kitchen waste disposal mechanism featuring legislation, franchising and collection-transportation-processing integration; (vi) a renewable resource recycle model based on 'Internet +' concept and enhancement of traditional ways; (vii) a remanufacturing technology service development model featuring directional repair, professional maintenance and post-contracting; (viii) an integrated industrial-urban development model featuring production-living links and collaborative production waste processing; and (ix) a statistical evaluation mechanism on regional resource output rates centred on statistics, calculation and self-evaluation (NDRC 2016a).

Future Plans

While setting a prospective target for GDP growth (averaging 6.5% per year), the 13th Five-Year (2016–2020) National Economic and Social Development Plan (NDRC, 2016b) set quantitative and compulsory targets in resource conservation and pollution control, for example, a 15% decrease for energy consumption per unit of GDP, a 23% decrease for water consumption per unit of GDP, a 15% reduction in SO_2 emission and a 10% decrease in COD emission. To fulfil the above targets, the 13th Five-Year plan put forward the 'Project Lead CE' among five key projects on resource conservation, with the other four being National Energy Conservation Action, National Water-saving Action, Construction Land-saving and Intensive Use, and Green Mining Development Demonstration Areas.

On 21 April 2017, NDRC along with 13 other relevant departments formulated and issued the details of 'Project Lead CE' (NDRC, 2017). The overall goals of this project are not only to draft the nation's green, circular and low-carbon industry strategies and to establish circular urban development models, but also to construct a new strategic resource security system, and develop a green way of life.

The project sets out specifics for the following tasks: (i) constructing a circular industrial system; (ii) improving circular urban development models; (iii) strengthening the resource recycling industry; (iv) enhancing institutional supply; (v) stimulating new momentum in circular development; and (vi) implementing major special operations. Many innovative concepts and technologies are to be promoted in the project, including the Sharing Economy, Internet plus Recycling, Green Consumption, Public-Private Partnerships (PPP), Institutional Innovation Experimentation Zone and the Green Credit Management System.

By 2020, the project aims to fulfil a 15% increase in the output of resources compared to 2015, a 73% comprehensive utilisation rate for industrial solid waste, an 85% comprehensive utilisation rate for crop straw, CNY 3 trillion in output value from the resource recycling industry, 75% of national industry parks, and 50% of provincial industry parks carrying out recycling transformation and 100 resource recycling demonstration bases in cities of prefecture level and above.

Success Stories

From 2005 to 2011, the responsible government agencies, NDRC, MEP, MOST, MOF, etc., organised two batches of national CE demonstration pilot projects and local governments carried out the corresponding pilot work. Over the years, the pilot projects have made some remarkable achievements, enriching theory and practice and making major breakthroughs with typical CE models emerging across a range of levels from individual enterprises, industrial parks to regions/cities. In order to speed up the adjustment of the economic structure, change the mode of development and construct a conservation-oriented and environment-friendly society, typical CE models were promoted across the country (NDRC, 2011c). The following three success stories were examples from those typical CE models.

1. *Tianjin Beijiang power plant (individual enterprises):*

An innovative CE development model for coastal power plants

Case description: Since its beginning, Tianjin Beijiang power plant has adopted the concept of CE in its planning and design, and constructed an industry chain of 'power generation – seawater desalination – sea salt concentration – salt chemical industry – new type building materials'. The results include a reduced dependence on coal, zero use of fresh water resource, zero discharge of waste water and solid waste and low emission of waste gas. This was achieved by the following five main initiatives.

(1) Tianjin Beijiang power plant follows the principle of 'Reduce First' through the use of an ultra-supercritical unit for power generation. This greatly reduces coal consumption, thereby reducing pollution from the source of coal burning.

(2) The plant utilises low-grade steam and waste heat from power generation for seawater desalination with an annual capacity of 72 million tons, 90% of which flows into the city water network, thereby providing a new effective solution to the water shortage problem in northern China.
(3) The concentrated seawater as a by-product of seawater desalination is utilised for salt production in Hangu Saltworks, which enables an annual increase of salt output by 450,000 tons and saves about 22.5 square kilometres of land.
(4) The resulting bittern from salt production is used to produce chemical products.
(5) The fly ash and desulfurised gypsum from power generation is used for production of new building materials.

Compared with 2005, 2010 witnessed a 746.9% increase in total production value, 7.4% increase in energy output rate, 34.4% decrease in sulphur dioxide emission, producing 8.8 million tonnes of fresh water, with 100% in both the comprehensive utilisation rate of industrial solid waste and reuse ratio of industrial water.

Case interpretation: The model of Tianjin Beijiang power plant and its environmental achievements are significant for the development of CE in coastal power plants through the construction of CE industrial chains.

2. *Suzhou Industrial Park (industrial parks):*

A CE development model featuring resource recycling and efficient utilisation for industrial parks with modern manufacturing and service industries.

Case description: Suzhou Industrial Park has promoted CE development in four domains, that is, industry structure, infrastructure, social consumption and living environment.

(1) Building a green industry structure: in the planning stage, according to the principle of achieving efficient and full use of resources, the park employed a structure comprising electronic information, precision machinery, biological medicine and new materials; in the construction stage, the types of park enterprises were strictly controlled according to CE-based admission criteria; in the stage of production, and the implementation of clean production, a symbiotic industry chain was built, based on electronic information manufacturing and electronic waste disposal, to form an integrated internal waste classification/recycling system and an external professional processing/recycling system.
(2) Constructing public infrastructure: implementing overall planning of circular infrastructure systems; construct water reuse, sludge disposal, waste heat utilisation, centralised heating and cooling facilities; employing energy and material exchanges to realise combined cooling, heating and power (CCHP), and the graded reuse of water resources including collected rainwater.
(3) Cultivating green consumption: construct CE consumption model based on community centres to achieve recycling and centralised pollution control.
(4) Constructing an ecological living environment: develop smart transport, utilise underground space and promote green buildings to provide residents with a healthy and comfortable living and working environment.

Compared with 2005, 2010 witnessed 113.4% increase in GDP, 12 times increase in output rate of land, 10.3% decrease in water consumption per unit of industry value added, 42.4% and 37.2% decrease in sulphur dioxide and COD emissions, respectively.

Case interpretation: The Suzhou Industrial Park model can be used as a reference in CE development for development parks in the restructuring and upgrading stage, including in new cities and developed regions.

3. *Ninghai Zhejiang (regions/cities):*

An urban development model based on CE demonstration areas for resource-poor regions

Case description: Ninghai County in Zhejiang province promotes the integration of primary, secondary and tertiary industries to achieve sustainable development through the construction of industrial, agricultural and eco-tourism CE demonstration areas.

(1) Ninghai Bay CE demonstration area utilises fly ash and desulfurised gypsum generated by power plants to build 'coal – power – fly ash – cement', 'coal – power – fly ash – new wall materials', 'coal – power – desulfurised gypsum – gypsum board' circular industry chains. Ninghai Bay also utilises waste heat from power plants in the construction of 'waste heat – central heating' and 'warm water – aquaculture farming' circular industry chains.
(2) Zhejiang East Coast agricultural CE demonstration area has constructed the 'straw –breeding – biogas, biogas residue/slurry – fruits/vegetables' circular agriculture chain, and formed 'planting – breeding – processing' integrated agricultural CE.
(3) Ninghai Bay eco-tourism area has adopted the concept of CE in planning and constructing coastal resort areas, and deployed waste recycling and water-saving measures.

Compared with 2005, 2010 witnessed 114.5% increase in GDP, 37.6% increase in energy output rate, 2.3% growth to 98.7% in comprehensive utilisation rate of industrial solid waste, 25% and 12.2% decrease in sulphur dioxide and COD emissions, respectively.

Case interpretation: The Ninghai case can serve as a model for economically developed yet resource-poor regions to develop their CE.

Conclusions

In its 11th and 12th Five-Year plans, China, facing increasingly serious resource challenges and environmental threats, has adopted CE as a new development model that helps China leapfrog into a more sustainable economic structure. China has successfully deployed a 'top-down' approach in developing CE, leveraging an array of financial, legal, administrative and institutional measures to do so. This chapter presented the key policy portfolio that has been driving China's CE achievement during the past decade.

With China moving into the 'new normal' of economic growth and building ecological civilisation, CE continues to act as a major strategy for the development of China's economy and society. While setting a prospective target for GDP growth (averagely 6.5% per year), the 13th Five-Year plan (2016–2020) National Economic and Social Development Plan (NDRC 2016b) set quantitative and compulsory targets in resource conservation and pollution control. This chapter introduced China's future plans in CE development, such as 'Project Lead CE' for 2016–2020, which is aimed at fulfilling the above compulsory targets.

Success stories of exemplary CE models were also presented at levels ranging from individual enterprises, industrial parks to regions/cities so that China's experiences in developing and adapting CE can be put into a specific context, and be drawn on by other countries also making efforts towards a circular and sustainable future.

Acknowledgements

The present work greatly benefitted from the generous time and insightful comments of the reviewers. The author would like to show his appreciation by thanking the reviewers for their assistance reviewing earlier versions of the manuscript.

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Chapter 4

Biosolids: The Growing Potential for Use

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Abstract

Biosolids, the residual solids from wastewater treatment operations and once considered a waste product by the industry, are now becoming increasingly recognised as a multifunctional resource with growing opportunities for marketable use. This shift in attitude towards biosolids management is spurred on by increasing volatility in energy, fertilizer and commodity markets as well as moves by the global community towards mitigating global warming and the effects of climate change. This chapter will provide an overview of current global biosolids practices (paired with a number of Australian examples) as well as discuss potential future uses of biosolids. Additionally, present and future risks and opportunities of biosolids use are highlighted, including potential policy implications.

Keywords: Biosolids; wastewater treatment technologies; anaerobic digestion; sludge-to-energy; agricultural use; nutrient recovery; circular economy

Introduction to Biosolids

In a wastewater treatment plant (WWTP), sewage is treated by separation of the liquid fraction from the solid fraction, with the latter commonly known as sludge. In the early 2000s, the Water Environment Federation in the United States proposed redesignating sludge as 'biosolids' to reduce its poor public perception and promote its beneficial use by industry (Spinosa & Vesilind, 2001). Fast-forward 16 years and biosolids are now widely used to describe wastewater solids that are suitable for beneficial use.

Before the advent of modern WWTPs in the early twentieth century, sewage was disposed untreated and biosolids as we know them today did not exist

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 67–88

doi:10.1108/978-1-78714-619-820181007

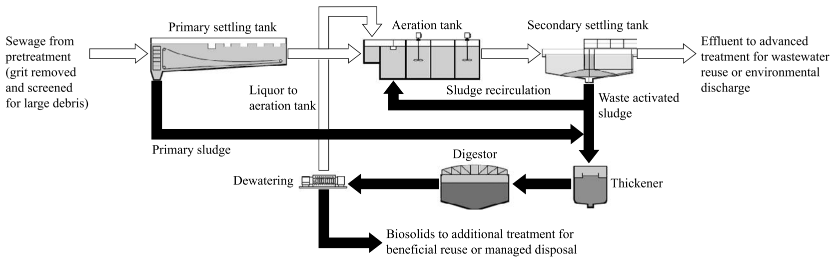

Fig. 4.1: A Typical WWTP Layout Showing the Sewage Treatment Process. Open Arrows Represent Liquid Streams and Solid Arrows Represent Solid Streams. *Source*: Adapted from Stamatelatou and Tsagarakis (2015).

(World Economic Forum (WEF), 2004). Treated biosolids have significantly reduced levels of labile organic and metal contaminants, odour and pathogens compared to raw sewage and contain high concentrations of nutrient-rich organics, making it safe for beneficial use as a dry-solid or wet-slurry product. Having similar consistencies to soil or compost, biosolids are well suited for agricultural applications, and as human civilisations have been using sewage and animal manure on crops for millennia, the logical direction of early biosolids use was in agriculture (WEF, 2004).

In the twenty-first century, biosolids use in agriculture still predominates, but more and more emphasis is being placed on maximizing the efficient utilisation of each resource component in biosolids (Peccia & Westerhoff, 2015). As such, technologies for energy generation from the organic matter in biosolids, nutrient extraction and recovery as well as improved agricultural utilisation with value-added biosolids products are being explored and adopted by water authorities around the world. Additionally, stricter environmental regulations and public fear of potential food and drinking water contamination from land-application of biosolids are shaping national policies and the direction of the biosolids industry. A recent example of public perceptions affecting biosolids policy is in the Nicola Valley region of Canada, where public fear of potential groundwater contamination from biosolids use has resulted in a review of local government policy on biosolids reuse (Fig 4.1; Kamloops, 2016; The Merritt Herald, 2016).

Background and Approach

The traditional model of our global economy has been the linear consumption of natural resources, focussed on extraction, use and final disposal of ‘waste’ material. In such a manner, natural deposits would over time be stripped bare of resources and in place be overwhelmed with man-made refuse, more-often-than-not damaging to the environment. In the biosphere, all natural life revolves around the circular motion of growth, decay and regeneration, running in perpetuity as resources are conserved and recycled for the propagation of new life. For example, plants grow, animals eat the plants, animals produce waste, waste is recycled back into the soil and new plants grow from recycled nutrients in the soil.

This concept of recycling and renewal of 'waste' applied to man-made infrastructure is the notion of the circular economy.

With regards to the human food and drinking water cycle, our wastewater treatment systems are engineered to mimic that of natural systems in order to process our sewage. Unfortunately, this imitation of nature is incomplete, with the shortfall being at the tailend of treatment systems. Traditionally, focus has mostly been on destroying disease-causing pathogens and treating sewage to safe-enough levels for environmental discharge and disposal. This is in line with the traditional economic model of linear consumption of resources and disposal of 'waste'. However, today, evolving scientific research and engineering innovations have seen the progression of technologies capable of producing value-added and cost-effective biosolid products ready for real-world applications. In line with anticipated global population growth and advanced wastewater treatment rollout, global generation of 'high quality' biosolids will continue to grow while already strained natural resources are subjected to increased pressure from overexploitation.

Modern human civilisations have grappled with the issue of readily available energy supplies since the Industrial Revolution to feed our technological advancements. Biosolids, although not able to fulfil all our energy needs, can still contribute to the future of our renewable energy mix, hence its pertinence in these discussions. Similarly, the need to cultivate food crops to feed our growing global population has seen the development and use of fertilizers to boost and sustain production. With natural resources becoming depleted, biosolids use in this space is a growing sector of industrial advancement. This chapter will present a critical analysis of the most active biosolids technologies for beneficial use currently being explored worldwide (renewable energy generation, agricultural use and nutrient recovery) and how these technologies can close the loop on biosolids, from a waste to a resource. Furthermore, policies and legislation aimed at affecting the use of biosolids will be discussed. This chapter will not discuss pathogen destruction, public health and safety or public perception and the economics of biosolids, as these topics are supplementary to the core discussion topics of this book as listed above. Additionally, there are more detailed works on these topics currently available in the literature.

Renewable Energy Generation

Biogas

Anaerobic Digestion. Although records in Western literature only date back to the seventeenth century AD (Abbasi, Tauseef, & Abbasi, 2012), the production and use of biogas can be traced back to the ancient Assyrians in the Tenth Century BC with the digestion of sewage said to be known to the Chinese in the same time period (He, 2010). However, it was not until 1897 in India, when the first purpose-built anaerobic digester (AD) was successfully erected to generate methane (biogas) from sewage at the Matunga Leper Asylum in Bombay (WEF, 2013). Since then, anaerobic digestion has become one of the two most widely adopted sludge treatment technologies in advanced WWTPs (the other being incineration) and continues to be further refined by utilities worldwide (LeBlanc, Matthews, & Richard, 2009).

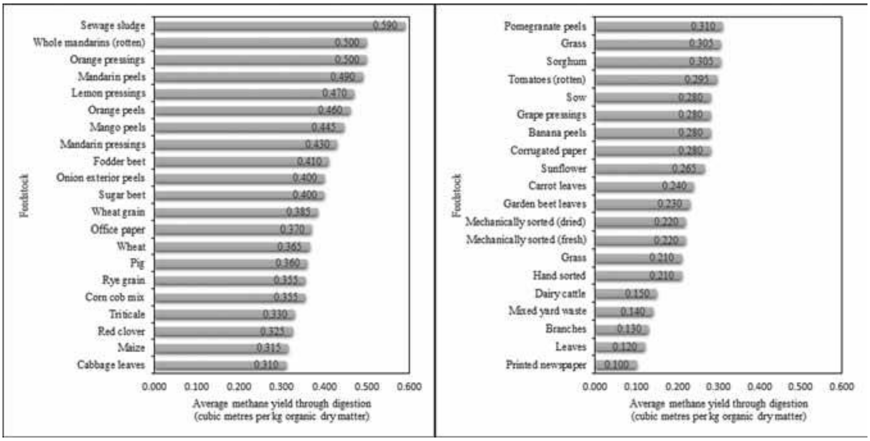

Fig. 4.2: Average Methane Yield of Different Types of Biomass When Anaerobically Digested. Note That Sewage Sludge Has the Greatest Potential Yield. *Source*: Adapted from Appels et al. (2011).

The Classical view of WWTPs being simply facilities of waste disposal has now shifted to a ‘resource recovery’ mindset, with one of the most significant recovered resources being energy. According to LeBlanc et al. (2009, Table 4.13, p. 70) global average diesel price more than tripled between 1996 and 2008, with electricity prices almost doubling during the same period. In the wastewater industry, it is known that the energy content of sewage is greater than that required for its handling and treatment (Heidrich, Curtis, & Dolfing, 2011) such that WWTPs can potentially become energy neutral or even energy positive; in fact, several such WWTPs already exist and the number is growing (Fig. 4.2; United States Environmental Protection Agency (US EPA), 2014; WEF, 2013).

Co-digestion. With ongoing improvements in efficiencies of sludge-to-energy conversion processes in WWTPs, energy self-sufficiency can be achieved and maintained purely by digesting sewage. An example of this is the Strass WWTP in Austria, which achieved self-sufficiency in 2004 after extensive optimisation and is currently regarded as industry best practice (Nowak, Enderle, & Varbanov, 2015). To complement optimisation efforts and help meet the goal of becoming energy positive, additional feedstocks can be fed to the ADs to enhance biogas production through a process known as co-digestion. In 2008, the Strass WWTP implemented co-digestion of kitchen waste, resulting in site electricity production of 180% that of consumption requirements and excess electricity was fed back into the grid (Nowak et al., 2015). Similar upgrades have occurred in the Netherlands with excess WWTP energy and biogas harnessed for beneficial use to supplement or offset grid power requirements. For example, excess heat from the Apeldoorn WWTP is being used to heat local homes and biogas produced by Den Bosch WWTP is being used as a green vehicle fuel or supplied directly to local industries (Stamatelatou & Tsagarakis, 2015). Across Europe in 2012, 137 plants were injecting methane biogas into reticulated gas networks, and this number is expected to continue growing (Hahn, Krautkremer, Hartmann, & Wachendorf, 2014).

Biogas production to supplement existing energy requirements is not just confined to Europe. On the other side of the world, a recent example of successful municipal co-digestion is the WWTP of Palmerston North City Council in New Zealand. From 2012 to 2014, the performance and stability of the AD with co-digestion was monitored and compared against an AD with just primary sludge. The feedstock for the AD with co-digestion is dairy trade waste with high fats, oil and grease content, and is added at a rate of 10–15 m^3/day to a 145 m^3/day primary sludge feed (Thiele, Burt, & Monaghan, 2016). On average, the biogas production was approximately 100–150% higher with co-digestion than the typical biogas productivity of the standard AD and the co-digestion AD had no reported stability issues (Thiele et al., 2016). In essence, biogas production was doubled by co-digesting modest amounts of an additional trade-waste feedstock (≈10% by volume) at less than 35% of the typical installation costs for new ADs (Thiele et al., 2016).

In the United States, WWTPs account for 3–4% of the country's electricity consumption, with electricity often the greatest single cost to these plants (>30% of total operational and maintenance costs) (Shen, Linville, Urgan-Demirtas, Mintz, & Snyder, 2015). Although the majority (48%) of total sewage flow in the United States is treated using ADs (544 WWTPs), less than 10% of these facilities recover the biogas energy, with most of it flared off (Shen et al., 2015). The US EPA estimates if all these facilities adapted combined heat and power technologies to harvest this wasted energy, the concomitant reduction in power consumption would be equivalent to offsetting the greenhouse gas (GHG) emissions of some 430,000 cars (McCarty, Bae, & Kim, 2011).

Liquid Biofuel

Benefits of liquid biofuel production from biosolids are analogous to that of biogas production in offsetting nonrenewable energy use, but have the potential to be even more significant. A key advantage of liquid biofuel is the ability to directly substitute existing fossil fuels with minimal to no modification to modern equipment while maintaining operating efficiencies. High liquid fuel-consuming sectors of the economy like heat and power generation, commercial transport (including shipping and aviation) as well as domestic transport, look set to benefit greatly from renewable biofuels and will have the greatest impact in offsetting global GHG emissions from this fuel type.

There is a growing body of research regarding conversion processes for producing liquid fuels from biosolids (Bridle & Skrypski-Mantele, 2004; Fytili & Zabaniotou, 2008; Leszczyński, 2007; Manara & Zabaniotou, 2012) and some of the technology has proven technically feasible. However, few examples of full-scale facilities exist, largely due to the higher cost of production compared to fossil fuels. Two examples of technologically proven, commercial biosolids-to-oil processes are EnerSludge™ and the Sludge-To-Oil Reactor System (STORS).

EnerSludge™ was first developed in Germany in the 1980s before the technology was acquired by Environmental Solutions International (ESI) in 1989.

ESI further refined the technology for a number of years before building the first demonstration plant in 2000 for the Water Corporation of Western Australia. The Subiaco WWTP in Perth operated with the EnerSludge™ biosolids-to-oil process for 16 months and gave positive energy returns; however, the plant was eventually decommissioned in favor of the cheaper process of liming biosolids (Kalogo & Monteith, 2008; US EPA, 2006). Additionally, the resulting oil was deemed unsuitable for the on-site diesel engines (US EPA, 2006).

The STORS technology has followed a similar history. Developed at the US EPA's Water Engineering Research Laboratory in Ohio, the technology was acquired by ThermoEnergy Corporation and expanded to commercial scale production in 1998 (Kalogo & Monteith, 2008; Molton, Fassbender, & Brown, 1986). A 5 tonne/day sludge-to-oil demonstration plant was set up at the Colton WWTP in California and converted biosolids to oil with 90% of the heating value of diesel (Kalogo & Monteith, 2008). An additional by-product was a solid char (biochar) which had similar properties to coal and both could be used for industrial power generation (Kalogo & Monteith, 2008). This facility operated for two years before being decommissioned in 2000 at the conclusion of the demonstration project (Kalogo & Monteith, 2008; US EPA, 2006; WaterWorld, 2001).

Despite the inherent difficulties of producing an economically viable biofuel product, the benefits associated with creating a renewable fuel source independent of volatile fossil fuel markets should be sufficient to justify future investment and rollout of the technology when market conditions are favourable. Research is ongoing in this area and future full-scale technologies will be spurred on by the associated economic and risk management benefits. In Australia, the burgeoning biofuel company Muradel is anticipated to achieve this goal in the near future with support from State and Federal Governments as well as the private sector (Changarathil, 2016; Muradel, 2016; The Australian Renewable Energy Agency, 2016). Muradel has been developing the process Green2Black™ as a means of converting algae grown in wastewater into biocrude. The advantage of this particular technology is the ability to accept various biomass feedstocks such as stockpiled biosolids and discarded rubber tyres (Muradel, 2016). Biocrude has been in production since 2011 at the company's first demonstration plant in Karratha, Western Australia, from 2011 and from 2013 is now being produced at an expanded South Australian facility in Whyalla (Changarathil, 2016). Initial production cost started at AUD$9.90 per litre in 2011 and has been steadily declining since, with the goal to be below AUD$1.00 per litre in the coming years (Changarathil, 2016). By 2018, it is expected that production levels of refinable biocrude from the facility at Whyalla will be up to 500,000 barrels annually (Changarathil, 2016).

Agricultural Use

Direct Application

As mentioned at the start of this chapter, the use of biosolids in agriculture has been and continues to be the dominant form of beneficial use. Biosolids generally

Table 4.1: Agronomic Value of Typical Biosolids Based on 2012 Fertilizer Values.

Nutrient	Typical Concentration (Dry Weight)	Mass Per Dry Tonne Biosolids (kg)	Value Per kg[a] (AUD)	Value Per Dry Tonne Biosolids (AUD)
N	4.0%	40	\$1.23[b]	\$49.20
P	2.5%	25	\$4.06[c]	\$101.50
Cu	550 mg/kg	0.55	\$13.00	\$7.15
Zn	800 mg/kg	0.80	\$7.00	\$5.60
	Total nutrient value per dry tonne biosolids (AUD)			\$163.45

Source: Adapted from Darvodelsky (2012).
Notes: Only N, P, Cu and Zn are included in these calculations as they represent the highest value constituents today. The value of organic matter and energy potential is not included in this valuation.
[a]Nutrient values are calculated from fertilizer prices from Landmark, Orange, excluding delivery.
[b]Based on lowest cost of nitrogen – urea.
[c]Based on lowest cost of phosphorus – mono ammonium phosphate.

contain 1–5% phosphorous (P) and 1–10% nitrogen (N) as well as significant levels of trace metals required by crops for healthy development (Darvodelsky, 2012; Latimer, Rohrbacher, Nguyen, & Jeyanayagam, 2015; McLaughlin, Warne, Stevens, & Penney, 2007; Pritchard, Penney, McLaughlin, Rigby, & Schwarz, 2010; Tyagi & Lo, 2013). This blend of nutrients, from an economic standpoint, makes biosolids a very attractive organic alternative to the use of conventional chemical fertilizers like diammonium phosphate (DAP). Table 4.1 illustrates the estimated agronomic value of typical biosolids:

Globally, land application of biosolids is considered to be the most sustainable use of this material (Darvodelsky, 2012). Additionally, biosolids use in agriculture can offset the use of chemical fertilizers which can have nonrenewable origins and require large amounts of energy to produce. Based on carbon footprint values of 4 kg CO_2 equivalence per kg N (European average for urea production) and 1.3 kg CO_2 equivalence per kg P (European average for mono ammonium phosphate production) (Wood & Cowie, 2004), for every dry tonne of biosolids used in agriculture, approximately 192.5 kg of CO_2 emissions are abated from avoided fertilizer production.

As of 2015, agricultural use represented 64% of all biosolids end use in Australia (up from 55% in 2010), and this trend is generally replicated internationally (Australian and New Zealand Biosolids Partnership (ANZBP), 2015). According to LeBlanc et al. (2009), the most common biosolids use option in middle and higher-income countries is addition to soil (Table 15.10, p. 66), with developing countries also expected to follow this trend as their economies and populations grow. As shown in Table 15.2, developing regions currently account for around 85% of global population; hence, the use of biosolids in agriculture will continue to be of future significance.

Table 4.2: Estimated Biosolids Production by Region Based on 2015 Population Size (United Nations (UN), 2015).

Region	Population (2015)	Estimated Biosolids Production in 2015 (dry t/y)	Equivalent Biosolids Production in 2015 If Developing Regions Had Similar Levels of Wastewater Service Coverage to Developed Regions (dry t/y)
Asia[a]	4,393,296,000 (60%)	9,928,849 (29%)	87,865,920 (+885%)
Africa[a]	1,186,178,000 (16%)	15,420 (negligible)	23,723,560 (+153,849%)
Europe[b]	738,442,000 (10%)	14,768,840 (44%)	14,768,840 (no change)
Latin America and the Caribbean[a]	634,387,000 (9%)	1,433,715 (4%)	12,687,740 (+885%)
Northern America[b]	357,838,000 (5%)	7,156,760 (21%)	7,156,760 (no change)
Oceania[a,c]	39,331,000 (1%)	387,141 (1%)	603,680 (+156%)
Total	7,349,472,000	33,690,725	146,806,500

[a]Calculations for developing regions are split into 2.26 kg/person/year (for Asia and Latin America and the Caribbean) and 0.013 kg/person/year (for Africa and Oceania).
[b]Calculations for developed regions (Europe and Northern America) are based on a conservative biosolids production rate of 20 kg/person/year from Gómez et al. (2010) with reference to LeBlanc et al. (2009).
[c]Biosolids production in Oceania is mainly from Australia (310,000 dry t) (ANZBP, 2015) and New Zealand (77,000 dry t) (ANZBP, 2016) and the remaining production is estimated using the 0.013 kg/person/year production rate. The value of 2.26 kg/person/year is calculated using data on China as an analogue and 0.013 kg/person/year from data on Brazil, Turkey, Slovakia, Hungary, the Czech Republic and Slovenia as analogues.

Blended and Heat-Treated Products

Liming, composting and heat-treatment (drying) are common processes for treating biosolids when the end-product is required to have a higher level of microbiological stabilisation prior to Governments. The result is three distinct product streams for agricultural utilisation with unique properties.

Limed biosolids are biosolids blended with liming agents such as calcium oxide or calcium hydroxide to destroy residual pathogens and minimise odour, as well as limit the attraction of disease vectors such as insects and other living organisms that can transport biosolids-borne pathogens away from site.

This results in products which have higher alkalinity, low heavy metal bioavailability, and these are well suited for use in heavily cropped fields or acidic soils requiring alkaline amendments. In Western Australia, the Water Corporation produces lime-amended biosolids from their Subiaco WWTP. Although this material is suitable to market as-is, blending with red clay has yielded a product known as Lime-amended BioClay (LaBC®). In addition to functioning as an organic fertilizer for acid sandy soils, LaBC® also overcomes water repellence, a significant issue of arid soil types like those found in Australia (Shanmugam, Abbott, & Murphy, 2014). On the market since 2011, LaBC® is sold to broadacre farmers as a three-in-one product to offset the use of agricultural lime and chemical fertilizers as well as to decrease the natural water repellence of sandy soils and increase their water-holding capacity (Shanmugam & Abbott, 2015; Water Corporation of WA, 2014).

Composted biosolids are biosolids blended with organic green waste and composted with similar results to liming in terms of volatile solids reduction, odour mitigation and residual pathogen inactivation. However, the final products have different properties to limed biosolids, in that pH is circumneutral and the consistency is like that of mulch or topsoil. Composted biosolids are well suited to horticultural and domestic use and as top dressing for fields. In Australia, Sydney Water has beneficially used 100% of its biosolids annually since 2003 and currently sets the national benchmark for beneficial use (Sydney Water Corporation 2012). Of that, 20% of all biosolids produced ends up in compost with approximately two-thirds of all compost products in Sydney containing a blend of biosolids (ANZBP, 2015; Darvodelsky, 2012). This practice is replicated throughout Australia and is common practice in the compost industry globally.

Heat-treated biosolids are biosolids that have undergone some form of drying which effectively kills all pathogens, concentrates the nutrients in the biosolids and significantly reduces the volume of material to be transported. As with liming and composting, potential odour and pathogen issues are mitigated during heat-treatment and the resulting products are essentially dried biosolids in a concentrated and commonly pelletised form. These heat-treated biosolid products can be applied in any agricultural, horticultural or domestic application requiring fertilizer use.

Unlike unmodified biosolids, blended and heat-treated biosolid products commonly attract a higher price due to the refined nature of the product. A well-established and often cited example is the heat-treated product known as Milorganite® produced in Milwaukee, Wisconsin. Touted as the gold-standard of biosolid fertilizers, Milorganite® was first marketed back in 1926 and as of 2016 had been sold for 90 years (LeBlanc et al., 2009). In 2006, the sale of 41,500 dry tonnes of Milorganite® throughout the United States and Canada resulted in a USD$5.85 million net revenue for the Milwaukee Metropolitan Sewerage District (LeBlanc et al., 2009). In Australia, a product similar to Milorganite® is currently being produced by the Ballarat North WWTP in Victoria (Fig. 4.3). The first of its kind in Australia, this facility has been in operation since 2008 and produces a dried, pelletised biosolids product which is sold to broadacre farmers in the region (AWA, 2016).

Fig. 4.3: Pelletised Biosolids from Ballarat North WWTP in Victoria. The Pellets Are >90% Dry Solids, Friable and Well Suited for Agricultural Spreading and Soil Incorporation.

Nutrient Recovery

One of the major challenges for the direct application of biosolids or biosolids products is the cost of transport to the agricultural site for beneficial use. For fresh biosolids, the majority of the transported mass is water (≈80–90%) and even with dried material, nutrients (N and P) only account for 10–20% of the total dry weight, with the remainder being less agronomically valuable organic and inorganic matter (Latimer et al., 2015; Tyagi & Lo, 2013). Additionally, chemical fertilizer prices have steadily increased in recent decades in line with finite natural reserves of phosphate rock and potash being limited to only a few countries (Dawson & Hilton, 2011; Karunanithi et al., 2015; Latimer et al., 2015; Van Kauwenbergh, 2010). This issue is exacerbated by the fact that fertilizer prices are strongly correlated to the crude oil price. Fluctuations in the global crude oil market in recent years have seen significant spikes in the cost of chemical fertilizers, peaking in 2008–2009 with some products more than doubling compared with 2006–2007 prices (Fig. 15.4). Due to these economic drivers, there have been significant recent advances in the development of technologies for nutrient recovery from wastewater and biosolids. The two main streams currently employed are

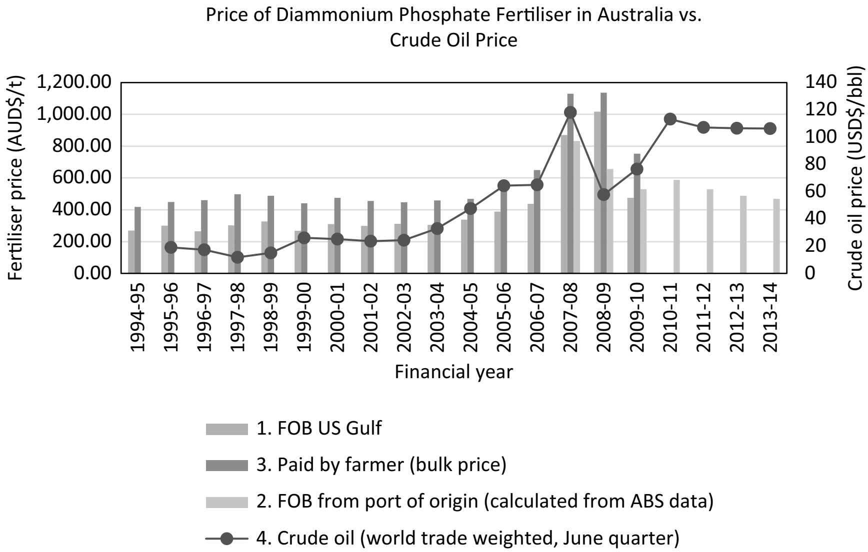

Fig. 4.4: The Price of DAP Fertilizer in Australia (FOB and Actual Cost to Farmers) Compared to the Global Crude Oil Price from 1994–1995 to 2013–2014. *Sources*: Data collated from the Australian Bureau of Agricultural and Resource Economics and Sciences (2010), Office of the Chief Economist (2014) and Bureau of Resources and Energy Economics (2011).

thermochemical (pyrolysis, gasification and incineration) and chemical precipitation processes (Fig. 4.4).

Thermochemical Processes

Thermochemical processes operate on the basis of oxidation, converting biosolids' organic matter into P-enriched ash or char at high temperatures. Pyrolysis and gasification are two-step processes that operate under low oxygen environments. Depending on the normal operating conditions (350–500°C for pyrolysis and >800°C for gasification), the first step will result in the production of syngas or oil which can then be combusted in the second step to produce energy (Bolan et al., 2013; Kalogo & Monteith, 2008; Latimer et al., 2015; Strande, Ronteltap, & Brdjanovic, 2014; Tyagi & Lo, 2013). The resulting solids can range from a char product suitable for use as a solid fuel to inert ash.

A well-documented example of pyrolysis technology is the SlurryCarb™ process. Developed in the United States by EnerTech Environmental, the low temperature (≈270–325 °C) slow pyrolysis primarily converts biosolids to a char product known as E-fuel intended for use as a replacement fuel to coal (Kalogo & Monteith, 2008). A commercial installation built at the Rialto WWTP in California has been in operation since 2008 and supplied E-fuel to local cement kilns. However, operations were discontinued in 2011–2012 for commercial reasons. The facility has since been acquired by Kore Infrastructure and was scheduled to be re-commissioned in 2016 with equipment upgrades to the facility (WaterWorld, 2015).

Where pyrolysis is a relatively mature technology, gasification is only now being commercially applied. The PYREG® process is currently installed at the Linz-Unkel WWTP in Germany and converts biosolids via low temperature gasification (≈650 °C) into syngas and a P-rich ash (Geraats & Kox, 2016). The generated syngas is combusted within the WWTP to recover energy and the nature of the equipment setup ensures maximum heat recovery. The generated ash has a minimum P_2O_5 content of 10% (up to 20%) and only 39% the mass of dry biosolids (90% mass reduction from equivalent fresh biosolids) (Geraats & Kox, 2016; PYREG, 2016).

On the opposing spectrum, undoubtedly the most established and widespread thermochemical process currently used is incineration. Unlike the incomplete oxidation processes of pyrolysis and gasification, incineration is the complete combustion of biosolids into ash and is a simple technology. Due to this simplicity, incinerators can operate with a wide variety of feedstocks and it is not uncommon to co-incinerate biosolids with other solid wastes such as municipal and construction wastes (Goh, Short, Bolan, & Saint, 2015). Additionally, incineration is a popular alternative to biosolids management where direct land application is not feasible and is commonplace in the United States and parts of Europe.

In Australia, only one biosolids incineration facility exists – the Lower Molonglo Water Quality Control Centre in Canberra. Operated by Icon Water (formerly ACTEW), this facility incinerates biosolids to produce 16 tonnes a day of a P-rich fertilizer known as Agri-Ash (Icon Water 2016). With an average phosphate content of 6.6% and 60% the neutralizing value of lime, Agri-Ash is successfully marketed as a lower cost alternative to chemical fertilizers and agricultural lime (Fertspread, 2013; NSW Department of Primary Industries, 2012).

Chemical Precipitation

One of the disadvantages of thermochemical conversion processes is the inability to recover N in the resulting product as it is oxidised and volatised at the high operating temperatures; hence, the development of chemical precipitation technologies to recover both N and P. First developed and implemented by countries such as Japan and the Netherlands where incineration is prevalent, chemical precipitation processes exploit the physico-chemical properties of magnesium and calcium ions in forming precipitates with phosphate and ammonium ions (Tyagi & Lo, 2013). Addition of magnesium and calcium solutions to solubilised biosolids or dewatering liquor results in the formation of magnesium ammonium phosphate (struvite) or calcium phosphate crystals which can be physically separated and further refined (Latimer et al., 2015; Tyagi & Lo, 2013).

Currently, struvite crystallisation is the most mature chemical precipitation process for nutrient recovery with efficiencies of 80–95% P and 4–40% N (Karunanithi et al., 2015; Latimer et al., 2015). Six commercial technologies (Airprex™, Crystalactor™, Multiform Harvest™, NureSys™, Pearl™ and Phospaq™) are presently operating at over 20 WWTPs globally (Latimer et al., 2015). Ostara, the company behind the Pearl™ process is the largest of these commercial entities and now operates a number of facilities globally, with several more currently in planning or construction phase (Ostara Nutrient Recovery Technologies, 2016).

Recently, the Metropolitan Water Reclamation District of Greater Chicago installed three Pearl™ 10,000 reactors at their Stickney WWTP in Cicero, Illinois, making it the world's largest nutrient recovery facility at time of commissioning (Marketwired, 2016). At full capacity, the facility will produce 10,000 tonnes/y of the granular struvite fertilizer Crystal Green with a nutrient content of 5% N, 28% P and 10% Mg (Marketwired, 2016).

Despite the observed increase in adoption of these technologies, the cost of nutrient recovery from wastewater and biosolids is still higher than the cost of conventional phosphate rock mining and industrial ammonia production (Tyagi & Lo, 2013; Van Kauwenbergh, 2010). However, because of increasingly tighter environmental regulation and the volatile nature of global fertilizer prices, the demand for alternative sources of fertilizers is growing and nations have begun to recognise the need for strategies and measures to safeguard their future nutrient security. According to the US Geological Survey (2016), Morocco (72.5%), China (5.4%), Algeria (3.2%) and Syria (2.6%) collectively control 83.6% of the world's phosphate rock reserves. Morocco currently holds the largest share of the global phosphate reserves due to its annexation of Western Sahara (which is not recognised by the UN) and the sovereignty and security situation of Western Sahara remains unresolved. Understandably, this resource security situation makes those nations dependent on P reserves quite anxious, and national policies are being activated to safeguard the future nutrient requirements of these countries. For example, Germany is now promoting the need for P recovery from various resources including sewage, with recent estimates indicating that P recovery potential from combined sewage and manure resources would be sufficient to satisfy national P demands (Wiechmann et al., 2015). In the United States, the agricultural sector requires 49 million tonnes of fertilizer (N and P) annually (Latimer et al., 2015). Of this, WWTPs can potentially provide 2–5% (100,000–210,000 tonnes) of the total P fertilizer demand and 2% (220,000 tonnes) of the total N fertilizer demand (Latimer et al., 2015). The value of struvite depends on its P-content, but it is estimated at between USD$0.75–1.00/kg excluding transport and vendor costs (Latimer et al., 2015).

On average, the human body excretes between 1 and 1.5 g of phosphorous every day (Van Drecht, Bouwman, Harrison, & Knoop, 2009). Utilizing country-specific projections, Van Drecht et al. (2009) calculated that the annual global output of P into sewage was 1.3 million tonnes in 2000 and is predicted to increase to some 2.4–3.1 million tonnes by 2050 (Van Drecht et al., 2009). With increasing global population and rapidly diminishing quality of finite extractable natural P resources, the demand for alternate P sources looks set to increase into the future, suggesting increased future relevance and demand for wastewater-derived nutrients.

Policies and Legislation

The safe use of biosolids requires legislation and policies to guide its management and application. The European Commission's 1986 Sewage Sludge Directive (86/278/EEC) was the first such regulation adopted by the EU to encourage the safe use of biosolids in agriculture (European Commission, 2010a). In 1993, the United States developed an independent policy called the Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503) (US EPA, 1993). Both these documents were based on the best scientific evidence of the day and seek to regulate the agricultural use of biosolids to protect human and environmental health. The EU Directive takes a more precautionary approach with biosolids use, and this stance has been adopted by countries like Australia and New Zealand (Council of the European Communities (CEC), 1986; Darvodelsky, 2012; New Zealand Water and Wastes Association (NZWWA), 2003; US EPA, 1993). Equivalent national and regional biosolids guidelines since then have been largely developed based on the EU Directive and the US 503 Rule.

Scientific evidence has shown that the recycling of nutrients from biosolids use is an effective substitute for chemical fertilizers, facilitating the conservation of mineral phosphorus reserves and offsetting GHG emissions from the production of chemical fertilizers. Therefore, current legislation is geared towards encouraging its use as an agricultural fertilizer. Compared to other types of organic fertilizers, the use of biosolids internationally is relatively low. In the EU, for example, biosolids use equates to just 5% of total manure use and is applied to only 5% of agricultural land (European Commission, 2010b). As such, there is still considerable future capacity in the agricultural sector for greater biosolids uptake in line with anticipated future production growth. Current EU biosolids use in agriculture is estimated at 42% of total supplies, with this value predicted to increase slightly to 44% by 2020 (European Commission, 2010b). While the beneficial effects of biosolids application on agricultural soil quality are well documented, biosolids are also successfully used in forestry and remediation applications (disused mines and landfills) and so there appears to be future scope for greater biosolids application to these alternate end uses in Europe and more broadly.

Improved source control (trade waste management) and effective treatment of sludge and biosolids have seen steady improvements in biosolids quality in recent decades, with declining levels of heavy metals and pathogens in the treated product such that biosolids use poses little human health risk with proper regulation and management. However, due to the ever-evolving nature of scientific development, new and emerging pollutants continue to be identified. In some developed nations, there are growing public concerns about the land application of biosolids stemming from issues such as odour, emerging pollutants, as well as the negative public perception of biosolids in general (Beecher, Connell, Epstein, Filtz, Goldstein, & Lono, 2004; Gale, 2004; Goodman & Goodman, 2006). As a result, the US 503 Rule is reviewed every two years to identify additional toxic pollutants – the latest is the 2011 review published in 2015 (US EPA, 2015). The EU Directive does not undergo such a rigorous review and updating process as Member States have generally adopted stricter national and regional standards to that of the Directive (European Commission, 2010a). However, due to increased biosolids production in the EU, implementation of new legislation and the need to assess the latest scientific research, the European Commission is currently considering revision of the Directive (European Commission, 2010a).

In the developing world, land application of biosolids is still the preferred option due to the lower costs and energy requirements needed for other more advanced uses. In countries with large agricultural sectors like China and Brazil, there are economic and political drivers to increase the use of biosolids in agriculture (Chen, Whalen, & Guo, 2014; Spinosa, 2011). However, much like the developed nations, public concern and uncertainties regarding the risks associated with organic micro-pollutants are limiting biosolids use in agriculture. Landfilling is also becoming increasingly less acceptable due to space limitations in some cases as well as the negative impacts associated with GHG production. In countries where land is limited and of high commercial value, there has been a shift away from land application and landfilling to incineration. Countries like Japan, South Korea and the larger cities in China are shifting more to incineration to handle the growing production of biosolids, with the residual ash being used in construction and as feedstock for cement products (Chen et al., 2014; Kalogo & Monteith, 2008; Spinosa 2011; Taruya, Okuno, & Kanaya, 2002).

Developments in climate change science and renewable energy policies are also influencing biosolids management; options for GHG mitigation and renewed focus on energy recovery and biofuel production are being reflected in new technologies. In May 2011, a United Nations report estimated that renewable sources of energy such as biomass could meet 80% of global energy needs by 2025 with the implementation of positive government policies (Shen et al., 2015). Practical examples of such recommendations are already being observed. For example, the US EPA under the expanded Renewable Fuel Standard (RFS2) recently qualified biogas as a renewable fuel able to generate Renewable Identification Number credits (tradeable 'currency' of the RFS2 programme) for producers (Shen et al., 2015). The US wastewater industry has significant potential to take advantage of this opportunity, with less than 10% of WWTPs currently capitalizing on biogas energy (Shen et al., 2015). In Germany, electricity production from renewable sources is stimulated by feed-in tariffs from the German Renewable Energy Act with 20-year guaranteed fixed prices (Hahn et al., 2014). This tool has been successful in the wide scale expansion of biogas plants in Germany which currently produces over 50% of Europe's biogas (Hahn et al., 2014).

Other alternatives to direct application of biosolids in agriculture or land-based use of biosolids are gaining prominence and government support globally, including incineration, energy recovery pathways and nutrient extraction. In Europe, the European Commission has adopted the Circular Economy Package with revised legislation proposed for waste management to encourage the reuse of waste (European Commission, 2015). Within this EU action plan under biosolids management, focus will be on waste-to-energy pathways and nutrient recycling (European Commission, 2015). Globally, much focus is already placed on energy recovery and nutrient extraction technologies as discussed earlier in this chapter. Expansion of mature energy recovery technologies such as anaerobic digestion (including co-digestion) and incineration with combined heat and power will be the norm, with upcoming innovations such as the production of liquid biofuel from biosolids in particular being intensely scrutinised. Additionally, the recovery of nutrients from biosolids to offset current reliance on mineral fertilizers is becoming more prominent for some nations as they move to shore up their resource security. Given sufficient time and the right market conditions, industrial-scale recovery of other valuable components in biosolids such as rare-earth metals (Peccia & Westerhoff, 2015) and re-purposing WWTPs as bio-refineries to harness biological enzymes and bio-polymers for carbon and chemical feedstocks (Sheik, Muller, & Wilmes, 2014) may become a commercial reality.

Discussion

With recent technological advancements and the gradual sway of industry and public perceptions, biosolids, once classified as a 'waste' product fit only for disposal, are gaining prominence in their ability to function as a resource. The continued use of anaerobic digestion for sludge treatment along with advancements in co-digestion technology and the continuous improvements in WWTP efficiencies are pushing treatment facilities to become more energy positive. As previously mentioned, a number of WWTPs are currently energy positive and able to export energy in the form of excess heat and biogas into local networks to power industries and be used as domestic fuel. There is also significant investment and development of technologies for the production of liquid fuels from biosolids, able to supplement our need of fossil fuels. In future, it is expected that more of these facilities will be able to generate renewable energy to feed our power-hungry population centres and industries.

In addition to energy generation, biosolids use in agriculture to offset the need for synthetic fertilizers is receiving more attention as natural reserves become depleted. Despite the current economic hurdle of profitability, many developed nations are forming policies aimed at facilitating the development and adoption of efficient nutrient recovery technologies to safeguard domestic agricultural operations. Furthermore, in developing nations the use of biosolids on land is still considered the most economically viable option for treated sewage. With ever-increasing coverage of wastewater networks across the developing world and the increasingly stringent environmental limits set in developed countries coupled with population growth, the production of biosolids is expected to increase proportionately over time.

Biosolids use has the potential to affect national fuel and food supplies and global climate security. Significant fluctuations in fossil fuel and commodity prices in recent years has spurred investment into alternative fuels and fertilizers able to be decoupled from market forces. Moreover, the physical isolation of natural reserves of fossil fuels and mineral deposits in pockets around the world raises the question of continued accessibility to supplies. With regards to climate security, there is significant scientific evidence to show that the continued utilisation of biosolids can offset significant amounts of carbon dioxide from the atmosphere. This is achieved from the replacement of fossil fuels and the offset of synthetic fertilizers required for agriculture. Due to the fact that there is still significant capacity for agricultural land to accept biosolids, it is expected that the positive effects of utilizing biosolids for emissions offsets will grow.

With continued improvements in biosolids quality and the ever-increasing efficiencies of modern processing methods, the positive returns from the utilisation of biosolids will play an increasing role in the circular economy. WWTPs, once regarded as the final treatment facility for sludge as a waste product, are now producing renewable energy and nutrient streams able to be fed back into the global economy. Developments in positive renewable energy policies, resource recovery strategies and the increasing acceptance of climate science are influencing biosolids management and are spurring continued advancements in this area of waste to resource.

Conclusion

Closing the loop via the utilisation of biosolids has seen the adoption of policies geared towards a circular economy. The potential for biosolids to be a tradeable commodity is coming closer to realisation as the global community transitions to low-carbon and zero-waste management solutions. Current options for the beneficial use of biosolids are largely centred on agriculture and land applications and are commonly impacted by broader market forces like commodity and fuel prices. As global populations grow, so too will the production of biosolids and the concomitant increased global food demands will continue to ensure the future relevance of agricultural use as the simplest and most cost-effective biosolids management practice. Additionally, as biosolids treatment and processing practices continue to improve, the removal of heavy metals from the extraction of valuable commodities, such as energy and nutrients, will result in a higher-quality final product, making the widespread application of biosolids easier.

Increasing public awareness and a growing global emphasis on environmental protection and sustainability is resulting in the recognition of biosolids as an important renewable resource in an era of declining natural resources. This shift in perception of biosolids, from waste to valuable resource, has helped drive the adoption of nutrient and energy recovery technologies. Developed nations, such as those in Europe and the United States, are actively expanding existing wastewater facilities to incorporate maturing nutrient extraction and power generation technologies spurred on by national and regional directives. Emerging economies such as China and South Korea are legislating to improve national biosolids management practices in order to better align themselves with the rest of the world and, additionally, benefit from the hindsight of the Western world and not repeat mistakes of the past (marine dumping, landfilling, stockpiling and open incineration). Overall, the adoption of biosolids as a resource underpins the real need for global economies to correctly manage biosolids use and resource recovery in line with the notion of the circular economy.

Acknowledgements

This research is funded by the CRC for Low Carbon Living Ltd supported by the Cooperative Research Centres programme, an Australian Government initiative.

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Part II

Consumption, Design and Behaviour

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Chapter 5

Considering ‘Waste Value’ in the Circular Economy

Hélène Cherrier, Meltem Türe and Nil Özçağlar-Toulouse

Abstract

Designing and manufacturing long-lasting things and minimizing the use of material resources are central concerns to the circular economy. Yet, repairing and repurposing objects, and the experiences and knowledge of those who extend the life of objects at the consumption level, are absent from discussions on the circular economy. Based on in-depth interviews focussing on practices of repair and repurposing within households, this article interrogates waste and its capacity to disturb, impede or provoke practices central to the circular economy. Re-considering waste within discussions on the circular economy is a way to bring to the surface the overlooked capacity of waste to enable or hinder household engagement in practices of repair and repurposing through waste’s heterogeneous and shifting components, sacredness and morality.

Keywords: Revaluation; value; waste; repair; repurposing; assemblage; Bennett

Introduction

The concept of the circular economy is increasingly influencing new industrial strategies for waste prevention, regional job creation, and resource efficiency. In most discussions of the circular economy, the focus has been on industrial and organisational capacities and competencies to design products that can be ‘made to be made again’ and to minimise the use of resources, along with using renewable energy. Whilst focussing on industry is crucial to the creation of quality products that can retain their utility and value over time, the aim of this chapter is to shift the emphasis to the end consumers, who are also determining actors in the development of a circular economy.

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 91–102

doi:10.1108/978-1-78714-619-820181009

In this chapter, we consider practices of repair and repurposing within households. Repair is restoring by replacing a part or putting together what is torn or broken. Repurposing is creating a new or a second life for an existent object by making some transformations to it. Contrary to recycling, practices of repair and repurposing do not usually require infrastructures and energy outside of the household to reprocess the original material and, unlike reuse, these practices draw on forms of engagement with objects often of no immediate use, the unwanted, worn-down, deteriorated, broken or outdated items that would otherwise be discarded.

Through practices of repair or repurposing, the residue of something that used to be valuable –identified as 'waste' – is given a second life. These forms of household waste engagement practices shift our attention away from conceptualisation of waste as 'an end point in a sequence of the declining value of an object' (Hetherington, 2004, p. 165), to a re-assessment of the value of what might otherwise be discarded (Brosius, Fernandez, & Cherrier, 2013). We thus approach waste as transient and shifting in value rather than the end of objects' life cycle. Considering the transient value of waste at the microlevel of everyday life of households broadens discussions of the circular economy to include a view of 'waste' as potentially engaging. In the following section, we highlight current governmental approaches to waste and waste reduction. We then discuss waste from the household perspective, how is waste dealt with through disposal? Following our theoretical lens, we provide findings from ten in-depth interviews with consumers actively engaged in practices of repair and repurposing. The analysis reveals a new perspective on waste as *actants* in practices of revaluing waste through its mutating materials, sacred references and links to morality.

Diverting Waste

Household waste and surplus materials are central to current discussions on dumping space and sustainability (Brosius et al., 2013; Cherrier 2012; Sheth, Sethia, & Srinivas, 2011). Studies have discussed how a throwaway culture now shortens the life cycle of an object, with an increasing number of still functional objects being discarded for aesthetic or minor functional improvements (Cherrier, 2010). In response, governments have invested in waste management, treatments and recovery as recycling and re-manufacturing. In this process, household engagement with waste management has been tied to awareness-raising and financial incentives around separation of recyclable products and the use of appropriate recycling bins and collection services. Along with diverting waste from the landfill, another, yet less prevalent approach has been to address waste reduction through prevention, and the implementation of refillable packaging, home composting or the promotion of such services as reusable nappies (Cox et al., 2010). Whilst these programs have undeniably influenced household waste attitudes and recycling actions, the focus has been to reshape household practices, thus leaving aside considerations of voluntary lifestyle changes and existing practices that can contribute significantly to waste reduction (Burley & Gregson, 2009).

Interests embedded in voluntary changes in consumption lifestyles includes arguments that we live in an unfulfilling and ephemeral world of overabundance and excess dominated by consumption, shopping and brands (Schor, 1998). Under conditions of excess, scholars have analysed the various ways in which consumers seek to distance themselves from overconsumption and opt for alternative ways of consuming, embedded in anti-consumption ideology and typified by downshifting and minimalist lifestyles (Cherrier, 2009; Cherrier & Murray, 2007; Schor, 1999), de-growth movements (Cherrier, Szuba, & Ozcaglar-Toulouse, 2012) or anti-consumerism (Odou & De Pechpeyrou, 2010). Cherrier and Murray (2007) refer to Fromm's *being* mode of existence, where individuals are critical towards the system and all that surrounds them. This critical reflection empowers them to engage with a proliferation of sites for identity construction and opens up the possibility of moving from a mode of existence of disenchanted *having,* to one of re-enchanted *being*.

Another approach to consumer engagement in waste reduction is to focus on disposal practices, including not only trading, recycling and moving waste out of the home but also practices of revaluing waste within the home through repair and repurposing. Below, we first explain understandings of waste in disposal studies. We then provide an object-oriented perspective, which permits us to interrogate moments of repairing and repurposing objects, how these moments occur and what triggers or hinders the revaluation of waste.

Interrogating Waste Through Household Disposal

Household disposal studies have predominately focussed on how individuals shift things considered 'waste' (e.g., the nonutile, unwanted, worn down, deteriorated, broken or outdated items) from the inside to the outside of their homes. These studies have looked at disposal performed in the interest of aesthetic, social or functional improvements, and through available disposal conduits, including recycling infrastructures and second-hand networks, and also through family members, friends or charities (Gregson, Meltcalfe, & Crewe, 2007; Kidwell, Farmer, & Hardesty, 2013).

Considering disposal as a process of shifting things from the inside to the outside of the home has recently been re-assessed. Hetherington (2004) argues that disposal should be understood as a question of 'placing absence'. He points out that objects stored or forgotten in the house have moved through a process of presence to effective absence, and argues that this movement should be considered in disposal studies. Likewise, Parsons (2008) understands disposal, beyond a question of moving object outside of the home, to consider value re-creation in the transformation and re-use of objects themselves. By extending disposal to a process of moving things through different functions and spaces within the household, these studies situate one of the major element of the circular economy, which is the revaluing of waste, in the everyday life of the consumer, and beyond the domain of industrial structures, new technologies and industrial policy.

Another point we would like to raise regarding studies on disposal and waste is the current focus on the individual. Most studies on disposal have considered waste as something consumers deal with through reflexive evaluation and strategic choices, as to when, to whom and how to dispose of objects. This process of selecting and managing waste is orchestrated to create a desirable memory, gain symbolic immortality and re-affirm and legitimise their relations with certain people (Arnould, 2000; Belk, 1988). For example, during times of transition such as coping with divorce, disposing of material objects helps consumers cut ties with their previous roles and undesirable identities and adjust to new roles, and build new desired identities (McAlexander, Schouten, & Roberts, 1992). In the context of old age, consumers dispose of objects to negotiate the continuation of legacy and self-extension (Marcoux, 2001). As such, consumers actively define what objects count and do not count as waste, and dispose according to their evaluation and sense of self.

However, what or who defines waste is not simply a matter of individual choice. Sociological studies reveal that things, objects or possessions also respond to dominating classifications of order/disorder and tidiness/untidiness (Douglas, 1984), and categorisations of pure/impure and clean/dirty (Collignon & Staszak, 2004). Objects which decay, are broken or unused, commonly adhere to classification systems of dirt and pollution within the home, leading consumers to discard them using socially acceptable disposal conduits (Dion, Sabri, & Guillard, 2014). Further studies show that objects can act-back and disrupt disposal (Gregson, Meltcalfe, & Crewe, 2007). An object's unknown history or particular material features, for example, can prevent its disposal as intended by consumers. Consider the numerous lingering objects cluttering homes and the growth of de-cluttering agencies helping consumers to deal with their waste (Cherrier & Belk, 2015; Cherrier & Ponnor, 2010). These studies show the difficulties consumers have in selecting what is waste and nonwaste within the home, and actively managing their domestic waste.

As such, waste is not simply inert matter, but reveals capacities to hinder, orient or facilitate household disposal and waste management practices. This perspective can benefit discussions on the circular economy in two ways. First, it emphasises that the ways consumers operate at the postacquisition state to extend the life of objects is not solely dependent upon sustainability values and a desire to participate in the circular economy. Second, it highlights the importance of the social and material composition of wastes, and their capacities to shape or orient waste management, thus challenging the idea that the success of developing a circular economy rests, in part, on the development of designing products that can be 'made to be made again' (Ellen MacArthur Foundation, 2013).

In the following discussion, we position this study alongside Jane Bennett's work (2010) and propose a new understanding of waste as 'vibrant matter' (Bennett, 2010).

An Object-Oriented Perspective

Predominately inspired by Jane Bennett's (2010) *Vibrant Matter*, we examine waste from an object-oriented perspective. Whilst the vibrancy of matter has been discussed in relation to food waste (Cherrier, 2017), we adopt this perspective to discuss waste within the home, including broken, unwanted, unused or nonfunctional objects lingering within the home. Adopting Bennett's (2010) perspective, waste is not merely passive and lifeless matter, but *active,* with a capacity to act on us.

Inspired by Bruno Latour's concept of actant, Bennett describes how debris, junk, stuff, unwanted objects and all organic as well as inorganic matters abandoned on the street, are not dead stuff or passive entity, but are, instead, live presences with capacities 'to make a difference, produce effects, alter the course of events' (p. iix). In her exploration of *Vibrant Matter*, Bennett (2010) argues that actants never act alone; they act only within assemblages, and they operate in conjunction with other things. There is no single 'doer', only a doing within a human and non-human assemblage, and it is through assemblages that things become alive (Bennett, 2010, p. 28).

To understand Bennett's (2010) concept of vibrant matter requires a brief review of thinking in terms of assemblage. Assemblage is primarily concerned with heterogeneous elements brought together in particular interactions (DeLanda, 2006; Deleuze & Guattari, 1987). Understanding waste as an assemblage of heterogeneous components makes it possible to consider the value of waste unfolding from the interacting of components within an assemblage of objects, and with broader assemblages. For example, a hammer is made of materials such as steel, fibreglass and rubber, and each element, the head and the handle, is assembled to form the material object. As an assemblage of material components, the hammer is itself part of larger assemblages with its components interacting with other objects, space, local arrangements, human awareness of the object's relevant use, social definitions and functions and competencies to hammer. As the material assemblage itself is wrapped in other assemblages, the hammer carves a specific territory in the habits, practices and norms (its 'territorialisation') that gives the assemblage a particular expressiveness and marks it as distinct from the surrounding milieu (Deleuze & Guattari, 1987). That is, as the material and household components of the hammer assemblage are brought into a stable relation, they constitute a specific territory. However, territories are constantly destabilised by evolving assemblage relations and relations with the surrounding milieu (Deleuze & Guattari, 1987). For instance, when the head and the handle are separated or when the head is melted down, the hammer assemblage is destabilised, causing it to lose its territoriality within the household (resulting in a *deterritorialisation*). Importantly, this deterritorialisation occurs simultaneously with a reterritorialisation (Deleuze & Guattari, 1987), as new flows and interactions emerge. Thinking in terms of assemblage predicts that the molten mass or separated head and handle elements can enter a new assemblage (*reterritorialisation*).

Drawing on assemblage thinking, Bennett (2010) suggests that wastes have the capacity to act as quasi-agents or forces with 'trajectories, propensities or tendencies of their own' (p. viii). This tendency does not result from the subject's quantification, prediction and control but rather from the incalculable, which Bennett identifies as 'thing-power': 'the curious ability of inanimate things to animate, to act, to produce effects dramatic and subtle' (Bennett, 2010, p. 6), which represents the agency of things, to come into existence through dynamic assemblages (Bennett, 2012).

Considering the vitality of waste has direct implications for debates on the circular economy. Bennett's (2010) conceptualisation of matter allows an approach to waste reduction that differs from the human-centric approach where waste is a passive matter to be collected, manipulated and transformed, and where the success or failure in actively converting the discarded into something of more value is the consumer's responsibility. Second, Bennett (2010, p. viii) asks 'how, for example, would patterns of consumption change if we faced not litter, rubbish, trash or "the recycling" but an accumulated pile of lovely and potentially dangerous matter?' The answer to this question lies in understandings of waste as a 'confederation of bodies', brought together not by individual will but by the shared experience of a problem (p. 109).

The Study

Ten in-depth interviews focussing on practices of repair and repurposing within the household inform this study. The interviews lasted approximately 85 minutes, on average. Informants varied in their age, gender, social class, occupation, education, family composition and housing. Each interview started with 'grand-tour' questions around the way individuals made sense of repairing or re-purposing some objects and not others. The questions focussed on the type of object, its materials and its connections with the owner's biography, past and present identities, social network, places, events and other objects within the home. Another set of questions related to the informant's perspective on sustainability, waste and consumer culture. The aim was to capture the possible sociomaterial tensions that emerged in their practices of repair and re-purposing, and how these tensions were negotiated. This second set of questions allowed them to reveal the possible constraining influences that the cultural imperative to waste might have on their practices of repair and repurposing.

Waste as 'Thing-Power'

Our informants were very enthusiastic about re-purposing and repairing objects. They discussed external support mechanisms provided by the government and local administration such as free public arts and crafts courses on sewing, knitting, glass and fabric painting, jewellery design and even some repair-work. Popular TV shows and online blogs on D.I.Y. and craft were also mentioned, as encouraging to 'make use of' rather than to let go of things. Moreover, our study shows that practices of repair and re-purposing respond to the mutation of things in terms of their material elements deteriorating and corroding in interaction with people and nature. We also note how waste is inscribed in the sacred, hindering or facilitating its conversion. Finally, our data reveals waste as a material manifestation of morality, having effects on the ways consumers relate to broader ethical, social and environmental issues (see Fig. 5.1).

Material Mutation

Rather than relating to one object as a whole, our informants often discussed repair and repurposing in relation to the diverse material elements that constitute the object. Important to repairing or repurposing the parts or elements of an object is that when an object is broken, the boundaries of that object's collection of parts or assemblage blur, and its material elements start to interact with other

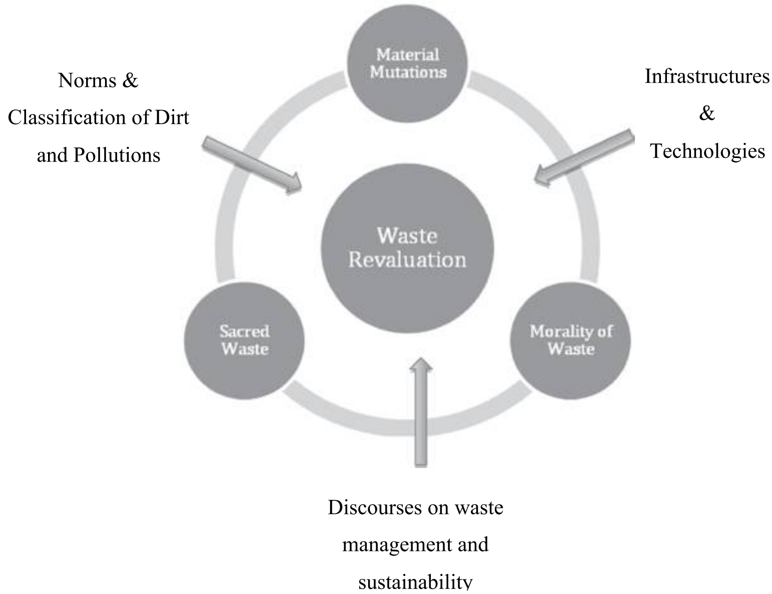

Fig. 5.1: Waste Revaluation.

(and usually broader) assemblages of materials in the household. Our informants explained the object's deteriorating, breaking or becoming outdated in interaction with its environment, such as a wooden chair becoming rotten in humid weather or a dress stained after a spill. The transition from something of value to declining worth not only fostered a new evaluation but also led our informants to re-consider not the object itself as a whole but its constitutive elements and their trajectories. We heard stories of informants disposing of some of the elements of an object whilst keeping other parts that were deemed repairable or transferrable to a new object assemblage. For example, when disposing of his beloved car that had been damaged during a car accident, Marc explained how he had kept the engine and disposed of the other elements of the car, with the intent to repurpose the engine. Similarly, Sally mentioned going through her clothes to check for and separate re-usable parts such as buttons or zippers. Lelise further explained disposing of the parts of her mobile phones, whilst keeping the phone chargers.

Waste revaluation through domestic practices of repair and repurposing is thus not simply about dealing with objects as a whole. Rather, revaluing waste demands knowledge of the various material components of the objects, their material properties and qualities. It also requires consumers to possess the necessary skills and competencies to de-assemble materials with rigid interlocking mechanisms. Rigid interlocking mechanisms refer to the fixed coupling of diverse elements forming an object that can often complicate disposal. Finally, waste revaluation calls for negotiations on the functional interdependencies of material components. Mobile computers, for example, were often mentioned in terms of their dependence on a charger, a docking station and/or a computer case. Although easily de-coupled (through some flexible interlocking mechanism), these components were perceived as interdependent, and thus hindered waste conversion.

Waste is thus relational and transforms, because materials mutate in interactions with other materials, and, in the process, demand various skills and competencies on the part of the consumers, in terms of responding and adjusting to often unpredictable, material mutations. Waste is thus in constant movement, and shifts through its interactions with other materials, as it does with people.

Sacred Waste

When discussing repair and repurposing, informants discussed broken things, outdated items and even unused items as often inspirational, leading to the creation and discoveries of new functionalities and usages. Interestingly, this inspiration not only concerned changes in the object's functionality and usage, but also concerned changes in the future life of our informants themselves. For example, Fanny often mentioned different possibilities for the future uses of objects, and wondered with excitement about her once functional object and its capacity to affect her life in the future.

> I have a few suits I cannot dispose of. I liked them when I first bought them and they fit me very nicely then…not that they are extremely valuable or anything, but I keep them. I feel maybe I can wear them if I get thinner. They are like 10 years old now.

Fanny's suits not only embody a past where she remembers having had a better appearance but, after many years, they have obtained an important role in her fantasies of her future self as 'older but thinner'. It is not simply the case that Fanny is projecting a future upon her suits. Rather, the suits, which are aging while preserving their appearance, as 'they still look nice and new', project onto Fanny an ideal version of getting old, challenging her to do the same and sidestepping their own disposal in the process.

The idea of sacred waste requires an understanding of waste's revaluation as more than a practice of people acting on a bundle of materials with properties of durability, movability or plasticity. Revaluating waste is not simply the result of infrastructures and technologies, nor the result of skills and competencies to convert waste to something functional and usable. As illustrated by Fanny above, with the passing of time, waste derives its significance from the persons and events to which it is connected, thus developing 'sacred' connotations for its users, and for others. These sacred relationships do not only reflect a subject having power over the object, but rather are more dynamic subject–object relations, in which waste gains power to act through its sacred connections.

Morality of Waste

The 'morality' of waste describes the deep connections between materials and the morality of those revaluing, circulating, or converting waste. That is, by proposing a morality to waste, we do not claim that objects do things instead of the subject, but argue instead, along with the object-oriented thinkers referred to above, that objects are participants or *actants* in the course of waste revaluation, through their connections with the morality of consumers.

It was clear from our informants' stories that practices of repair and repurposing were reflective of an engagement with their morality in terms of protecting loved ones (i.e., safe repair), preserving the natural environment (i.e., repurposing using existing materials), reducing social inequalities (i.e., providing materials to those in needs) and providing for tomorrow (i.e., repair for possible future usages). That is, consumers, through their waste (i.e., production, circulation, consumption of waste including repair and repurposing waste), show responsibilities towards people, society and the planet more broadly.

Informants discussed their waste in connection with broad issues such as the depletion of natural resources and various guidelines for environmental preservation. In their narratives, unused, broken or damaged objects and their material components belong to categories of matter with distinct properties (i.e., paper, plastic, steel, aluminium), and as such carry within themselves the owner's moral views of specific belongings and their environmental impact. Alice's washing machine *blew up*, and was thus transformed from being and acting as a *washing machine*, with a capacity to wash clothes, to being a no longer functional *appliance*. As a nonfunctioning appliance, the object took on new roles, including a moral one, based on its material compositions, the interlocking mechanism of each component and the classification of matter these brought to the fore. One of the moral roles of an appliance is its recyclability and as such, this demands specific caring practices. These caring practices include placing the object in a recycling facility, or, as in Alice's case, de-assembling the object to keep some of its parts for repurposing, thus not only extending the life of some of the object's parts within the home, but also engaging with political discourses that promote recycling as beneficial to the natural environment. Importantly, the 'morality' of the object problematises waste revaluation by raising questions about how the object aligns with waste politics, waste regimes and problems of waste impact.

Along with their caring for people and the planet, consumers, through their waste, connect with the well-being of society as a whole. Whilst objects provide consumers with a comfortable life, their accumulation can also highlight social inequality and imply wastefulness. From our interviews, it was clear that practices of repair and repurposing were experienced with the pleasurable feeling of not having to purchase, to accumulate, and thus to contribute to our overconsuming society. Revaluating waste can thus be said to carry within itself a 'morality', to share and participate in the well-being of humanity.

Whilst individuals negotiate the value and the symbolic meaning of waste during processes of waste revaluation, waste is in constant interplay with the sensibility of its owner, and raises issues of social justice and environmental degradation. Instead of being passive, waste, as discussed in this study, plays a role in our collective future in various ways, enabling, constraining or directing its conversion and circulation.

Implications

New ways of designing quality products and manufacturing things using less-resource intensive processes remain central to the circular economy. Yet, repairing and repurposing objects, and the experiences and knowledge of those who extend the life of objects in use, are notably absent in discussions of the circular economy. This paper addresses this lacuna by looking at practices of repair and repurposing within households.

Understanding practices of repair and repurposing as part of a transition to the circular economy helps reframe waste revaluation beyond waste treatment, transformation and recycling in purely productive and industrial terms. As our findings have shown, waste revaluation takes place within the household, and not just beyond its walls. Considering waste revaluation at the household level shifts attention away from simply removing waste, towards the possibility of embracing waste as both socially and materially productive and engaging.

Our findings show that waste revaluation through practices of repair and repurposing involves what Bennett terms 'thing-power' (2010). Rather than consumers dealing with waste as a means of self-expression, of group affiliation, of remembrance or self-projection (e.g., Price, Arnould, & Curasi, 2000), our study shows consumers responding to the material mutation, sacredness and morality, in their interactions with waste. That is, waste is not passive, succumbing to the functions, role and imprint ascribed to it by the individual consumer. Rather, waste is an *actant* and as such exerts effects on its revaluation. Waste is in constant movement as materials transform with the passing of time, changing in and through their interaction with their environment. Waste interacts with systems of classifications of order and cleanliness (Dion et al., 2014), but also with personal life stories, often challenging institutional and homogeneous understanding of what is waste. In connecting to life stories, waste can become a means by which consumers can reach the sacred, highlighting the power of waste to act as sacred stuff and consequently hinder or orient its revaluation. Waste also connects with the morality of consumers. Because waste transforms and changes in relation to its environment, it may create guilt, anxiety and provoke feelings of care, and thus orient consumers towards the morality of things, and the larger issues of waste in our society.

In sum, waste revaluation through recycling, repairing and repurposing is ultimately the result of human decision. However, in this study, we highlight the power of waste to orient, hinder or facilitate its revaluation through its mutating materials, sacredness and morality. As such, we break from the object-consumer dualism to consider waste revaluation where people, materials and contexts are participants in the process.

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Chapter 6

Circular by Design: A Model for Engaging Fashion/Textile SMEs with Strategies for Designed Reuse

Jen Ballie and Mel Woods

Abstract

Fashion/textile small- to medium-sized enterprises (SMEs) are currently adding value to previously discarded textile waste by applying practical skills, knowledge and expertise to rework and reuse this material. As a result, sustainable design strategies such as zero-waste pattern-cutting, design for disassembly and upcycling are beginning to emerge. However, the scope for redesign will always be limited and the complete lifecycle of the material used needs to be considered at the front-end of the innovation process, to optimise material lifespans and reduce consumer waste. Further work is also required to inspire and educate the next generation of designers to the creative potential of reuse, and help the industry to understand its viability, scalability and role in the future. This chapter explores how the principals of the circular economy might support business model innovation within fashion and textiles. To this end, an exploratory canvas tool for SMEs, 'Circular by Design', was devised to aid SMEs to embrace closed-loop systems and to identify the most appropriate sustainable design strategies for their business.

Keywords: Sustainability; design, textiles; fashion; circular economy; business models

Introduction

We live in a 'throwaway and replace' culture. Our growing population and demand for new products has placed huge pressures on our planet's resources. Our economy is locked into a system that favours a linear model of production and consumption,

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 103–121

doi:10.1108/978-1-78714-619-820181010

where resources pass from sourcing to disposal in a 'take-make-use-dispose' cycle. Climate instability, volatile commodity prices, ocean dead zones, vanishing forests, stalling economic growth, expanding food insecurity and resource conflicts are all now linked to this resource to waste linear economy (Grayson, 2008). Any of these are surely justifiable reasons to explore a new pattern.

The circular economy is a new construct being positioned as a solution to address complex issues around resource use and material waste. It goes beyond recycling by sustaining the more efficient flow of materials through a circular system, where resources are kept in economic use for as long as possible. When we consider that there are an estimated 6 billion consumers in the world today, the scale of throwaway consumption means that a huge amount of waste is continuously produced. As a result, industries such as textiles, for example, fashion, apparel, interiors and manufacturing are experiencing raw material shortages and resource price increases (WRAP, 2012). The fashion and textile sectors are addressing this through implementing sustainable design strategies, such as zero-waste pattern cutting, design for disassembly and upcycling (Earley & Goldsworthy 2017; Rissenan & McQuillian, 2016), but the scope for redesign will always be influenced by the first lifecycle of a garment, which includes the impact of design, production, consumption and use. For this reason, it is necessary to fully consider the complete lifecycle at the frontend of the design and innovation process, in order to optimise the opportunity for multiple lifecycles and to work towards reducing postconsumer waste.

However, further work is required to inspire and educate the next generation of textile and fashion designers to the immense creative potential of reuse and to help the industry to understand its viability, scalability and role in the future (DeCastro, 2014). Within the UK textile sector, there is increasing awareness of the requirement for new textile initiatives to be linked with the concept of the circular economy, but there is a lack of practical and accessible evidence available to provide support for this initiative (Earley & Goldsworthy, 2015). The circular economy offers a new avenue for design, but designers will need to learn how to adopt a more proactive, systems-based approach that truly 'closes the loop' (Goldsworthy, 2014).

This chapter focuses specifically on the practice of textile and apparel in the UK to consider a more holistic approach for designing and manufacturing within these sectors. First, we introduce a resource called 'Circular by Design', which was developed by the authors and piloted within a workshop with the aim of exploring sustainable design strategies within the circular economy model. We discuss the utilisation of this 'Circular by Design' resource to promote a more 'joined-up' approach, made possible by considering strategies for connecting stakeholders across the supply chain. Through a series of sustainable design strategies, a possible future scenario is explored to help emerging textile designers learn how to utilise waste in a more productive way, within the circular economy model. This chapter closes by reflecting on the implications of this research and the role of the textile designer therein, to highlight the significance of design-led approaches in strengthening communication, promoting creative action and embedding collaborative ways of working within the circular economy model. We conclude by making a recommendation for further research to consider how the global textile industry, higher education (HE) and researchers might collaborate to develop new models in the future to enable a more considered circular approach to textile and fashion design. While the chapter focuses on textile and fashion design, it is worth acknowledging that the issues discussed will have resonance but differing implications for other disciplines and industry sectors.

Methods and Approach

We propose the term 'Circular by Design' here to explore how the circular economy might provide a new construct for designers through which they can address the complex issues around material waste and subvert linear models of design, production and consumption within the context of fashion and textiles. The project started from considering ways of identifying the most appropriate design-led approaches to address gaps in knowledge and practice through connecting fashion and textile designers with other stakeholders across the supply chain. To be able to fulfil this aim, we explored the following research question: *How does the concept of* circular by design *engage textile/fashion small- to medium-sized enterprises (SMEs) with strategies for designed reuse?* We adopted a qualitative and inductive approach to answering our question, with a focus on secondary data, supported by semistructured interviews with three fashion designers from SMEs interested in implementing circular economy practices within their businesses.

To expand upon the concept of 'Circular by Design', we developed a canvas tool as a resource to provide a visual reference for discussing circular innovation. The literature suggested that whilst the economic imperatives aligned to the circular economy are understood, there was less clarity around the practical application of circular innovation within the fashion and textile sectors. Our research aimed to engage directly with industry stakeholders to identify where challenges or opportunities might emerge and to promote a more integrated approach by considering strategies for connecting stakeholders across the supply chain. Research for 'Circular by Design' was initially presented to sector experts at the Scottish Textiles Symposium (2014) and insights gathered from this event. Building upon this, a canvas tool was then developed alongside a call for participation, which successfully recruited a cohort of fashion/textile SMEs, from which three were selected to participate to test the tool in a pilot study. The research articulated in this chapter reflects and draws insights from that pilot, alongside referencing supporting literature, to support the work towards a circular future where materials are designed, produced, used and disposed of in radically new ways.

Circular Innovation within the Fashion and Textile Sector

Through a review of the wider fashion system, it is apparent that changes are emerging in response to a call for a more circular economy (Goldsworthy & Earley, 2016). Within the UK alone approximately 10,000 garments are thrown out every

10 minutes (Kerr & Foster, 2011). Conventional methods of dealing with these issues have been described as being symptom-based, and they have not addressed continuous and rising consumption levels. The garments in question are designed in response to regularly changing trends that enable quick profit (Niinimäki & Hassi, 2011). To start to address the required change, a greater value needs to be placed on consumer use, attachment and stronger 'user-product' and 'user-manufacturer' relationships (Chapman, 2005; Niinimäki & Hassi, 2011). Due to the low cost of high-street fashion, combined with a lack of service offered post-consumption, it has become more cost-effective for consumers to dispose and replace a garment once it has served its purpose. The whole economic system in the industrialised world is now based on a fast replacement of products and planned obsolescence (Jackson, 2009), and the field of fashion and textiles is no exception. The concept of planned obsolescence prompts the shortened life cycle of products to ensure a market need for future products (Walker, 2011). There is a further disparity created through a present disconnection between designer, process of manufacturing and the consumer, who is often left unsatisfied with their garment in the long term, which again encourages the rapid replacement of these products (Chapman, 2005).

From a review of the wider fashion system, it became apparent that changes are emerging in response to a call for a more circular economy (Goldsworthy & Earley, 2017). Fashion systems are now moving beyond material innovation towards a circular economy to support systemic change globally. However, whilst some designers and businesses within the textiles and fashion sector understand the term 'circular economy', they are generally less familiar with how this can be applied. By exploring the concept of the circular economy within the context of fashion and textile design in the UK from the designer's perspective, we aimed to provide a deeper insight into how this concept could support a circular approach in practice.

Whilst interrogating the modus operandi of the circular economy in the fashion and/or textile sectors, it also became possible to interrogate the role of design, and what the circular economy could mean if universally adopted by design practitioners. Andrews (2015) positions the circular economy as a radical new concept which is being advocated but as yet not widely practised. The work of Black (2012), Fletcher (2008), Tham and Jones (2008) and Earley and Goldsworthy (2017) expand upon sustainability within the fashion and textile context. Fletcher (2010), a founding scholar of the slow fashion movement, calls for a re-examination of the entire design, production and distribution process within the sector. Prior to these publications, fashion and textile design practitioners within the industry had to adapt sustainability arguments and theories from product design and architectural design writers, such as Chapman (2005) and Manzini (2005). In his talk titled 'Design, Ecology, Ethics and the Making of Things' McDonough (1993) presented an impassioned plea to undo the wrongs of the industrial revolution, stating that:

> If we understand that design leads to the manifestation of human intention and if what we make with our hands is to be sacred and

> honor the earth that gives us life, then the things we make must not only rise from the ground but return it, soil, to soil, water to water, so everything is received from the earth can be freely given back without causing harm to any living system. This is ecology. This is good design. It is of this we must now speak.

This early call to designers to perceive themselves as borrowers and active custodians of materials rather than just users was built on some years later in the seminal book *Cradle to Cradle,* by McDonough and Braungart (2002).

More recently, the economic value of textile waste has gained some attention, and there has been more interest in profitable opportunities to reuse end-of-life clothing, which, in addition to being worn again can be cascaded down to other industries, to make insulation or stuffing, or simply recycled into yarn to make fabrics that save virgin fibres (McKinsey & Company, 2013).

The RSA's 'Great Recovery' programme is focused on the concept of 're-making', which taps into wider trends of micromanufacturing and disruptive design (Thomas, 2015). This is defined as a series of manufacturing steps acting on an end-of-life part or product to return it to as new or better performance, with warranty to match (Gray & Charter, 2007). Thus, it is not just about rethinking the fundamentals on the supply side but also about redesigning the business on the demand side, especially as it concerns user-experience and rethinking value creation for consumption. Designers are learning that co-creation, rather than individual authorship, is becoming a more effective way to understand and meet these social needs, and new tools and platforms are becoming more effective in this regard (Thackara, 2013).

The concept of the circular economy presents a wider scope for exploring alternative fashion and textile models for reuse (Ballie, 2014), for example, through service design extending the life of garments in use through leasing and lending. This is part of a shift towards trans-materialisation, a term introduced by Waddell and Labys (1988), and service design has taken the concept and evolved it in parallel to product design development, in response to scenarios of use, reuse, design and redesign. However, to work this way, designers need to acquire new skills, knowledge and experience to enable them to act as social innovators and become agents of change. This is being explored through the Engineering and Physical Sciences Research Council (EPRSC) funded Re-Mantle and Make project (Ballie, Smith, & McHattie, 2016), a feasibility study exploring how maker spaces might be used as local educational hubs to support designers to test circular innovation within the textile sector through distributed manufacturing.

The Role of the Fashion/Textile Designer

We propose that by exploring the concept of the circular economy within the context of fashion and textile design in the UK, and furthermore from the designer's perspective, we may provide deeper insights into how this can be achieved. With 80% of a product's environmental impact determined in the design phase, there is a compelling reason to explore the role that designers can play in the development not only of new products but of new economic models (Andrews, 2015).

In this chapter, the term 'designer' is applied only to fashion and/or textile designers. However, it is worth acknowledging that traditional design disciplines are no longer clear-cut categories in the design professions, and that new hybrid roles are emerging, particularly within the area of systems and service design. This might imply that these new hybrid designers are better equipped than many to apply a more strategic approach to their business, however it cannot be the designer's responsibility alone to change whole supply chains. While we have sustained design capabilities within the UK, we are in danger of losing our manufacturing skills due to the decline of polytechnic training courses and reduced opportunities for vocational training (Taylor & Townsend, 2014).

Businesses also must begin to develop design briefs around new business models that take account of provenance, longevity, environmental impacts and end of life. There is limited literature relating to the role and specifics of ethics within the fashion or textile industry from a designers' perspective, and one that acknowledges their responsibility within the supply chain and the lifecycle of a garment. Traditionally fashion designers 'do not write, or theorise; they cut and make'. Designers can play a different role in supporting business experts, but to fully adapt to a circular economy, their responsibility cannot be undertaken in isolation. The circular economy goes beyond the capabilities of discipline specific designers and requires a collaborative systems approach to connect design, production, consumption and waste management.

It is worth highlighting here that circular design might be disruptive as it aims to subvert the notion of designing 'out' waste by identifying opportunities for designing 'in' this 'waste', to be reused again. Thus, we have expanded upon the work of Goldsworthy (2014), who claims that designers should perceive themselves as borrowers, and become custodians as opposed to users of materials. This goes beyond the commercial aspects of business (Porter, Stern & Green, 2014), and must include all stakeholders, including community along with individuals and their tacit knowledge and skills, which can become valuable assets in this collaborative process. There is scope for the fashion and or textile designer to play an influential role by conceptualizing designs that embrace circularity through re-thinking the use of materials to inform new manufacturing processes. The consumer or 'end user' becomes pivotal to circular innovation as they can act as conduits to close and re-connect loops after they have served their purpose, to enable materials to be re-appropriated through extended re-use, redesign, or reformation.

'Circular by Design' as a Concept

The authors have applied the term 'Circular by Design' across a range of events (Design in Action, 2014–2015), and as a headline for promoting a holistic approach to circular design and innovation. Toolkits and innovation resources have flourished in recent years, as a way of scaling the take-up of proven approaches, and has allowed design strategies to enter other disciplines and sectors. Notable examples include IDEO's Human Centred Design toolkit (2010), Frog's Collective Action toolkit (2011), Nesta's DIY Toolkit (2014) and Kimbel & Julier's Social Innovation toolkit (2015).

Another example, created to facilitate the design of a circular economy business called 'Circular Business Board' (Maslin & Shayler, 2014), was an adaptation of the business model canvas (Osterwalder & Pigneur, 2013). In this, Maslin & Shayler (2015) identified resource input and output, reverse channels and end-of-life strategy, as essential components. This business model was found most useful as it aligned with the same key principals in our 'Circular by Design' project.

However, the development of such tools requires a number of stages prior to the implementation in a workshop. Supported from a theoretical and methodological basis, this includes identifying the key questions and objectives that the tool will address. It also includes a design development phase where the design of the tool is done in such a way to support the desired outcome, the success of which is then measured through a reflection period.

The authors adopted a formalised four-step approach to scoping, developing, testing and piloting a Circular by Design model and canvas tool. In order for tools to be taken up and outcomes be useful for practitioners, testing requires the participation of key stakeholders to ensure it is robust, fit for purpose and aligned to user-needs. The approach detailed below indicates the stakeholder groups that were involved in the tool development at each phase. Step 1 positioned the questions, theory, objectives and outcomes as well as initial design approach by the authors and tested with a wider academic group. Steps 2 and 3 engaged sector experts who were vital to ensure any theoretical positioning reflected current real world challenges or application in the sector. The final pilot at step 4 was conducted with a target audience for the tool. At this stage, the authors worked with designers operating at an early stage of their textile start-ups or SME, whose ambition was to understand and adopt a more circular approach in their business proposition.

1. Development of a Circular by Design model and resource (included authors and team).
2. Scoping Study and Survey (included textiles sector experts and broader communities of interest and practice).
3. Peer review of Circular by Design Model (included textile experts, academics).
4. Piloting the 'Circular by Design' Tool (with designers via interviews targeted to the textiles start-ups and SMEs).

1. The 'Circular by Design' resource (see Fig. 6.1) was developed to mediate opportunities for integrated thinking and practice by supporting designers and businesses alike, in order to identify opportunities for closed-loop innovation. This model encourages designers to consider, in some cases for the first time, what could happen to a product or service both during development and after use. This model initiates deeper consideration of end-of-life strategies at the beginning of the design process, achieved by plotting different assets and stakeholders across the supply chain. These assets might be fibres, processes, materials, techniques, people, technologies, knowledge or expertise to visually

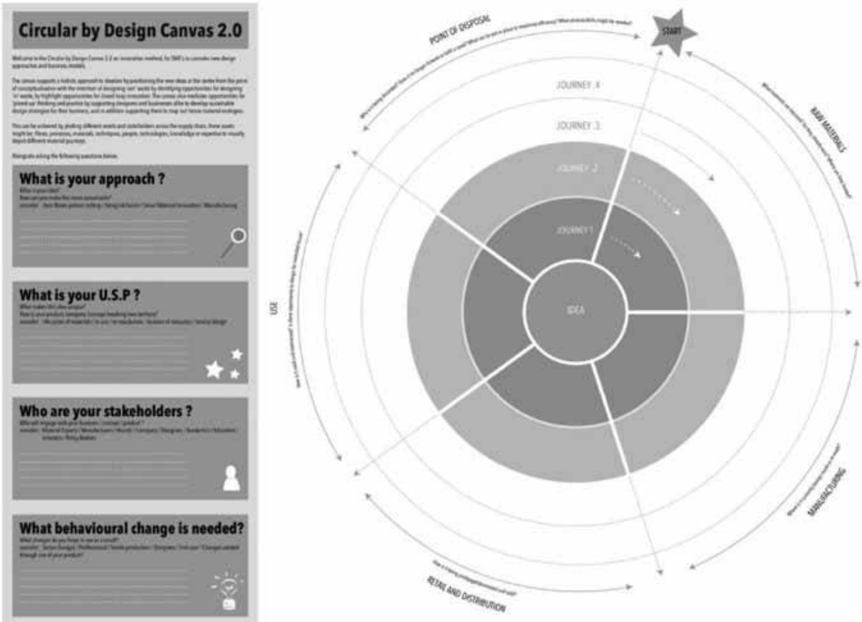

Fig. 6.1: Circular by Design Canvas. *Source*: Rissenan & McQuillian (2016).

depict different material journeys. The following questions were asked of the designers at step 4, who were interviewed:

- Who are your stakeholders?
- What is your design approach?
- What is your original contribution?
- What behaviour change is required in order to sustain a circular model?

The practice of designing for the circular economy involves 'precycling', that is action now to prepare for resources to remain as future resources in the economy or in nature (Greyson, 2007). For example, materials can be precycled by implementing sustainable design strategies and identifying end-of-life interventions. Any designed product has the potential to be precycled by preparing for re-use, remanufacture or even replacement by a service.

2. The scoping study and survey focused on piloting and testing the 'Circular by Design' canvas as an innovation method, to help SMEs consider new design approaches and business models. The aim was to identify and expand upon the capabilities of SMEs to embrace closed-loop innovation by using the canvas to identify the most appropriate sustainable design strategies for their business, and in addition supporting them to map out future material ecologies. We were particularly interested in extracting information around

existing and emerging strategies alongside identifying any gaps across the supply chain.

According to Scottish Enterprise, there is a lack of resources for R&D and business model innovation in the textile sector of the business community (Scottish Enterprise, 2013). However, Scottish-based fashion/textile SMEs are currently adding value to discarded textile waste by applying their practical skills, knowledge and expertise to rework and reuse this discarded material.

The authors delivered a session titled 'Circular by Design' within the Scottish Textile Symposium (November, 2014). The purpose was to gain deeper insight into how the textile and fashion sector understood the concept of the circular economy through the application of a Likert Scale survey exercise. This involved presenting a series of five statements to a public forum of approximately 100 delegates, with everyone provided with four postcards and invited to respond by holding up a card to show their level of agreement or disagreement on a symmetric agree–disagree scale in response to five statements. It is important to acknowledge this method was applied in a public setting and the results could be subject to some bias, as some present might have felt an obligation to comply with their peers. However, this method was used to initiate a conversation with the sector, and the discussion that emerged between each statement provided a deeper insight into the group's level of awareness, understanding and confidence. Approximately 63 people from academia, business and policy participating across the textile and fashion sector were present and took part. The statements presented to them are listed here:

- I understand the term 'circular economy'.
- I am not sure how to apply the 'circular economy' as a concept to my work.
- It is my responsibility to consider the complete lifecycle of my product or service postconsumption.
- I am being supported in introducing more sustainable practices within my business.
- In your business, consumers place a higher value on products/services produced with sustainable credentials.

After each statement, a Likert scale of 1–5 captured a broad sweep of their views which were captured by researchers who were stationed in the room to record their views. Following this, individuals were encouraged to write a qualifying statement on a small 'speech bubble' sheet which helped stimulate group discussions in a reflection exercise that followed. The exchange of statements extended the reasoning behind each individual's choice of a particular rating. These discussions were also captured by the team and provided a rich array of insights from the attendees.

3. Following the Likert scale exercise, a first draft illustration of 'Circular by Design' canvas was presented to the delegates. This was fundamental to capturing feedback through peer review from attendees who were all operating within the Scottish textile sector. This session confirmed that issues exist

that prevent sector progress towards a circular economy, including a lack of resources for R&D innovation and a need to foster links and catalyse knowledge exchange across the textile supply chain. It was important to note there was an enthusiasm for cross-sector collaboration. This pre-pilot scoping exercise allowed the research team to prepare the next phase of the project by crafting conversations to expand upon these issues in their complexity and entirety (Figs. 6.1–6.3).

Following on from the event at the Scottish Textiles Symposium, the authors sought additional responses through an online conversation. To achieve this, a Twitter hour was hosted (February 2015) using #circularbydesign with the same five statements disseminated online. To assist the discussion, Circular Innovation experts from the textile and fashion sector (Earley & Goldsworthy, 2015) were invited to respond by drawing upon their personal expertise to further support this conversation. Approximately 32 Twitter users responded and 200 tweets were documented. The feedback session showed that while people were responsive and willing to engage with the concept of the circular economy, they lacked confidence and acknowledged there were limited practical examples available for them to follow or adapt. Sustainable design strategies such as zero-waste pattern cutting, upcycling and design for disassembly are becoming more widely adopted, but these remain small scale. This data from Twitter reflected the findings from the Likert scale activity.

4. Finally, the Circular by Design canvas was presented to SMEs from the UK fashion and textile sector to support three semistructured interviews. The canvas was applied to align the conversation within the scope of the circular economy from a design perspective, with questions framed around the

Fig. 6.2: Circular by Design Canvas in Practice. *Source*: Ballie and Woods (2014).

Fig. 6.3: Likert Scale Responses to Provocation 'I Understand the Term "Circular Economy"', Scottish Textile Symposium (November, 2014). *Source*: Ballie and Woods (2014).

interviewees" business practices. The canvas was introduced to provide an overview of a material journey from the point of conceptualisation by positioning the textile assets in the centre and working progressively through each stage of the lifecycle, from raw materials, to manufacturing, retail and distribution, use and reuse, through finally to product disposal. The rationale for interviewees to engage in the research was twofold: they were intrinsically motivated to use the tool in order to reflect upon the application of circularity in their existing business; and they were also enthusiastic about having their feedback captured in order to support the tool's development and to widen access.

Summary of the Dialogue and Insights from SMEs

This section focuses on insights from the three selected SMEs who participated in semistructured interviews aligned to the Circular by Design Canvas. The Table 6.1 depicts an overview of the findings that were transcribed and then analysed using thematic analysis. The table highlights sustainable design strategies that are currently being adopted by these SMEs, alongside an overview of their original understanding of the circular economy, indicating both incentives and barriers.

Circular by Design Example 1: Extending Material Flow by Reusing Postconsumer Waste

SME 1 was focused on identifying business and design opportunities for reclaimed fashion waste because they had access to sourcing abundant surplus and unsold stock. The challenges of deconstructing existing garments were acknowledged – there are

Table 6.1: Documenting Semi-Structured Interview Insights.

Case	Sustainable Design Strategies	Knowledge of Circular Economy (CE)	Incentives to Adopt CE	Barriers to Adopt CE
SME 1	Strategically works with postconsumer waste and begins with end-of-life strategies. This involves streamlining upcycling techniques to support remanufacturing. Strategically exploring opportunities to rework existing garments and has developed tacit knowledge of the skills and resources required.	Understands the business implications of managing postconsumer waste. Would like to identify mechanisms to measure environmental and economic impact.	Highlighted that there is scope for collaboration with external stakeholders, the importance of not working in isolation. Niche market opportunities and the importance of constructing a narrative around reworked products. Service design approaches provide reduced material impact and can be implemented at a lower cost.	Working with fashion buyers existing lead times and quantities are not possible within CE. Won't work with fast fashion retail waste due to it being less durable. Military surplus provides more durable existing products for remaking. Turns down commissions often if the business case is not strong enough. Tacit knowledge and experience is not being sustained across generations.

SME 2	Design for disassembly. Open source fashion design innovation.	Expertise of smart energy efficiency within the building industry and familiar with tools to measure impact. Aware of the CE and its relevance in sustaining material efficiency.	Exploring outsourcing production through social enterprise initiatives to support local manufacture.	Expressed a difficulty sourcing sustainable materials. There is a lack of provisions for fashion/textile designers manufacturing within the UK. It is not yet possible to outsource small production runs.
SME 3	Focusing on long life garments. Sustainable material innovation using natural and environmentally friendly dyes, materials and supporting local manufacture.	Interested in garment lifecycle analysis and establishing a relationship with the end user to extend garment life.	Exploring a design collective concept to combine skills and produce diverse capsule collections.	There are challenges sourcing sustainable materials within a small quantity. Within trade shows, sustainable fabrics are in limited supply.

Source: Ballie and Woods (2014).

many limitations due to fabric quality, it takes longer to deconstruct than it does to produce using virgin materials, and therefore the retail cost is often higher for a second-life garment. New concepts for reworking this previously discarded waste are being piloted in partnership with HE fashion and textile students. This business owner had engaged with emerging fashion graduates to co-design capsule collections, and innovative new design approaches were applied to produce samples. However, the vast majority included intricate detailing that required an investment in skill development and time allocation. This was unsuitable for his business model, as the garments could not retail at a higher price point. The next sample collection focused on streamlining the process and designing a range of generic pattern cutting templates with detailed instructions for reproducing discarded garments.

This business owner declared that while there is a wealth of creative solutions apparent, they are often not always economically viable. The overarching goal would be to identify a series of design guidelines for defining if an existing garment had potential to be remade. This would include interrogation of the fabric quality and durability, the ability to seamlessly reconstruct the textile waste to ensure it looked as good as an original, and finally to streamline the remaking process to make if efficient and cost-effective.

Circular by Design Example 2: Extending Material Use through Design for Disassembly

SME 2 was focused on developing a lifestyle brand and designing a multifunctional collection for women's wear. This followed the premise of designing a series of modular garments that could be designed to be reconfigured and styled to wear in multiple combinations. In this case, considering mono materiality to ensure that each garment could be easily taken apart and recycled at the end of life, further extended the circular innovation approach. The initial garments had also been designed through application of zero-waste pattern cutting to minimise waste across the supply chain. Additional time has been invested in sourcing the most appropriate materials and the full design and production process had been considerately designed to reduce waste and to maximise material use. This business has invested a huge amount of time into conducting extensive research into sourcing, sampling, production development and retail marketing. This business is operating on a small scale, and all production of a small collection is being currently managed in house, which has allowed an agile business model to emerge.

This business has positioned itself with a strong unique selling point to appeal to the sustainable fashion consumer. The design investment into developing this collection using high-quality materials and production processes has led to a higher retail price. To extend material use, the right fibre and fabric are very important, and there are currently limitations for independent designers who wish to source eco-materials due to large minimum order requirements. Additionally, in-house production cannot be sustained in the long term for this business, and micromanufacturing facilities will be required in the future.

Circular by Design Example 3: Extending Material Lifespan through Design for Longevity

SME 3 was focused on designing a capsule collection of tops in collaboration with other designers. These garments are produced locally and made by hand using the finest recycled silk and organic cotton. The print process applies toxic-free and water-based inks and the entire production process is managed in-house within Scotland. Vintage 'Tops' are also sourced and hand printed to expand upon the collection. Following over 20 years of experience in the fashion industry, the founder adapted her business model and also works towards mentoring and supporting emerging designers.

The tool provoked conversation around the lifecycle of each top, and this business is focused on sustaining long-life garments. Additional features might be included in the future to allow owners to exchange and swap their garments online. It might be possible to lease the 'Tops' or allow the customer to trade them back to redeem credit for their next purchase. There is a desire to expand upon the business and source a building that provides an educational space for emerging designers and consumers alike.

Reflection on the 'Circular by Design' Canvas

Each of the Circular by Design examples are inspired by motives such as new business opportunities, an urge to innovate, greater resilience against future risks and eliminating environmental impacts. The circular economy is the same underlying imperative, whether people are focusing on ecology, economy, or their own business approach. Simply deciding that it must happen creates new spaces for ideas and actions on a relevant scale of ambition. Fortunately, a large-scale system change is no more complex to achieve than the small-scale system change, and redesigning a product or business as an example of the circular economy (Greyson, 2014).

The development and implementation of this tool and interviews conducted provided a valuable insight into the feasibility and applicability of the circular economy. Delivering economic value was not a primary driver and other forms of value emerged, such as the ability for the business to capture economic, social and environmental value for a broader range of stakeholders. When discussing their design strategies, all three businesses were focused upon changing consumer habits towards longer-life textiles and apparel and demonstrated an interest in producing garments that are easy to care for, repair, upgrade and recycle. Each business thought consumers were open to behaviour change as evidenced by Hawken, Lovins & Lovins (2013), who argue that not many years ago people would have been incredulous at the idea of recycling plastic bottles, yet this is now commonplace behaviour. However, there are real barriers facing businesses and others responsible throughout the whole lifecycles of their products and materials. Each of the businesses discussed an interest in adopting new business models such as social enterprise approaches and scaling-up production, and recognised that the circular economy might bring greater employment opportunities, especially in local entry-level and semiskilled jobs, and support the possibilities of remanufacture and the benefits that this could bring.

The authors' future aspiration for the development of the tool involves working towards catalyzing new and innovative approaches to design, promoting repair and reuse and encouraging service and leasing models for material recovery, with the premise of fostering innovation to support closed-loop innovation.

Conclusion

The current literature demonstrates limited practical examples of circular innovation within the textile sector, and that it was unknown if it would be truly possible to implement closed-loop innovations and on what scale. The practical examples within this chapter reveal a different story and suggest how we might expand upon the role, skills and capabilities of the textile designer to equip them to operate within a circular economy. Practically, this means businesses have the potential to unlock hidden potential from their supply chains, experience and materials. Moving forward, practical case studies will be essential in pioneering circular innovation alongside new business model development and support.

From the outset, it has become clear that there are varying levels of complexity in becoming circular through design, due to a lack of transparency within clothing and textile manufacture, where stakeholders are often disconnected. However, the textile and fashion sectors might not truly embrace this new way of thinking or operating, until their existing modes are proven beyond doubt, through direct experience, to be failing (Chapman, 2002). The tool was further refined within a residential innovation workshop under the same title, 'Circular by Design' (Design in Action, 18–20 March 2015) facilitated in partnership with Zero Waste Scotland, with the aim of creating new and innovative business strategies. Following this, further work is being undertaken to position the tool as a resource for emerging businesses to design for circularity, from the point of conceptualisation. This requires collaboration beyond the design sector. New roles might begin to emerge in response to this move towards the circular economy, for example, end-of-life specialists, fashion service designers or material recovery experts. The authors anticipate the canvas will document these design approaches, identify stakeholders, value propositions, and finally highlight what behaviour changes are emerging within this circular model.

While this chapter focused on textile and fashion design, it is worth acknowledging that the issues discussed might have different implications for other disciplines and industry sectors, but there might also be synergies and similarities for further exploration in the future.

Acknowledgements

The authors would like to thank the delegates who attended the Scottish Textile Symposium (2014) organised by the Scottish Textiles and Leather Association and Zero Waste Scotland for their time and contribution to this research. This research was funded by the AHRC through the Design in Action Knowledge Exchange Hub (Grant number: AH/J005126/1).

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Chapter 7

The ByeBuy! Shop: Testing Shopping Scapes in a Circular Economy

Kirsty Máté

Abstract

Conventional shopping-scapes are designed to promote a linear form of consumption. Products are moved from production systems through consumer distribution nodal points. The consumption of commodities through these points is promoted as the main, if not only, legitimate activity of shopping centres. A circular economic (CE) paradigm offers an alternative to the current model of linear consumption so that there are restorative processes to ensure products, components and materials are valued at all stages of product life (Ellen Macarthur Foundation, 2013). However, this model, like its contemporary linear model, overlooks the opportunities for more socially rewarding consumption that could particularly be addressed through the shopping scape. The ByeBuy! Shop was conceived to test ideas on an alternative shopping scape to increase social engagement and reduced consumption without the use of money for exchange. Accordingly, it is used here to exemplify a CE paradigm.

Keywords: Shopping, shopping-scapes; alternative economies; circular economy; retail design

Introduction

While the principles for the concept of a circular economy (CE) – especially designing out waste, building resilience through diversity, shifting to renewable energy sources, making use of systems thinking and treating all waste as resources or food (EMF, 2013) – have been discussed for a long time (Braungart & McDonough, 2002; Frosch & Gallopoulos, 1989; Hawken 1993; Hawken, Lovins, & Lovins, 2000; Hawkins, 2006; Murray, Skene, & Haynes, 2017), global interest

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doi:10.1108/978-1-78714-619-820181011

in the CE has been primarily evident over the last decade, with particular interest and uptake since the inception of the Ellen MacArthur Foundation (EMF, 2013). The CE's principles are steered by the fundamental drivers of constraining resources by eliminating waste and reducing the use of nonrenewable resources, increasing and developing new technologies and digital innovations to enable viable business alternatives, and decoupling resources from economic growth. This can empower consumers to gain increased value from products and assets, creating multiple socioeconomic opportunities (Lacy & Rutqvist, 2015). Economic growth remains an important tenet for the CE (Stuchtey, Enkvist, & Zumwinkel, 2016) despite contrary research on the benefits of reducing growth to create a more sustainable society (Hobson, 2013; Jackson, 2016; Lorek & Fuchs, 2013; Parker, Cheney, Fournier, & Land, 2014).

These principles of the CE have many advantages over the current linear economic model of 'take-make-dispose' (EMF, 2013) regarding particularly the use and waste of materials and nonrenewable energy. These changes, it is argued, will provide for a more resilient economy, and one that reduces '…dependency on resource markets, and a means to reduce exposure to resource price shocks as well as societal and environmental "external" costs that are not picked up by companies' (EMF., 2013, p. 10).

However, this chapter explores whether the CE (in its current form) is the panacea able to inspire the disruptive changes in consumption required for a resilient and sustainable future, or whether there are some critical changes needed before it can make this claim.

Does the CE Offer a Holistic Approach to Sustainable Consumption?

Let us first look at how others define sustainable consumption. Through the examination of a range of broad definitions of sustainable consumption, Tim Jackson observes that while some definitions focus on consumer behaviours and lifestyles others favor more efficient production processes and sustainable products. A distinction is also made between '…consuming more efficiently, consuming more responsibly or quite simply consuming less' (Jackson, 2006, p. 4).

Lorek and Fuchs (2013) and Hobson (2013) argue that there are 'weak' and 'strong' approaches to sustainable consumption where the focus of 'weak' approaches '…is primarily on improving the efficiency of production–consumption…' (Hobson, 2013, p. 1083) '…within the context of existing institutions and power structures and continued economic growth' (Hobson, 2013, citing Bailey et al. 2011; see Table 7.1).

Gill Seyfang (2009) argues that a new economics is required for sustainable consumption, embodying the following characteristics: '…localisation, reducing ecological footprints, community-building, collective action, and building new infrastructures of provision' (p. 61). These indicators provide not only a social and community focus for sustainable consumption but also offer self-reliance, reduced consumption options and new values relating to wealth, work and progress.

Table 7.1: 'Weak' and 'Strong' Approaches to Sustainable Consumption.

Key Facets	Weak Approaches	Strong Approaches
Central tenet	Improve material, social, and institutional efficiency of the prevailing production–consumption nexus.	Displace current foci of 'growth' and 'the economy' with non-consumption concepts and practices.
Methods	Technological innovation, voluntary, multiscale interventions; limited use of non-voluntary measures.	Diverse grassroots movements and communities; ontological displacement of growth and the economy in modernity.
End Goal	Continued economic growth alongside improved socioecological well-being.	Multilevel sociopolitical transformation that bring non-consumption-based well-being to the fore.

Source: Adapted from Hobson (2013).

Strong sustainable consumption focuses on consumer behaviours and lifestyles, by consuming less (Jackson, 2006); by displacing current foci on 'growth' and 'the economy' with nonconsumption concepts and practices Hobson, 2013; Lorek & Fuchs, 2013; or by providing a social and community focus (Seyfang, 2009). The CE's approach however to sustainable consumption is focussed on efficient production processes, sustainable products, consuming more efficiently and consuming more responsibly (Jackson, 2006). A 'weak' approach is therefore forged, focussed on improving the material, social and institutional efficiency of the prevailing production–consumption nexus (Hobson, 2013; Lorek & Fuchs, 2013), rather than engaging with the cause, consumption itself.

The CE's rather weak references to the social dimension, one of the three pillars of sustainability (environment, economy and sociocultural), is shared by authors such as Murray et al. (2017) and Hobson & Lynch (2016) who argue for its urgent inclusion within the conceptual framework of the CE. Murray et al. (2017) expose the loud silence of this dimension within the CE, while it concentrates on '…the redesign of manufacturing and service systems to benefit the bio-sphere…It is unclear how the concept of the CE will lead to greater social equality, in terms of inter- and intra-generational equity, gender, racial and religious equality and other diversity, financial equality, or in terms of equality of social opportunity' (p. 376).

Hobson and Lynch (2016) also argue that more radical approaches to issues concerning the social, the citizen and consumption need to be addressed to encourage a *diverse*, rather than the singular economy, still underlying the concept of a CE, which does not radically interrupt the current neoliberal paradigm. This concept of a diverse economy, offered by Gibson-Graham, Cameron, and Healy (2013), is a more wide-ranging, comprehensive, and multiple template, exemplifying values based on an economy of community, and recognizing cooperative, collaborative forms of exchange that do not necessarily include a financial benefit.

Within the CE, platforms for exchange include different forms of commodity exchange, including: sharing, product services, repair or recycling. These are typically forms of social innovation, cooperation and collaboration, but are proffered as platforms for reducing impacts to the biosphere through efficiency and responsibility, rather than as a requirement for transitioning to a more resilient society. As April Rinne (former chief strategy officer of Collaborative Lab) concurs the social component of the sharing economy, which emphasises human relations, is not necessarily included in the CE, which is focused on production for consumption (Lacy & Rutqvist, 2015). While idle goods in a CE are used to create and capture economic value (Hobson & Lynch, 2016), I argue that there are other human and social values (the non-material dimension of economics), enabling and supporting the material principles of the CE.

Ezio Manzini's model of a society which values social innovation, includes 'social economies' where barter and charity blur the boundaries of production and consumption, 'sociotechnical systems', where new social forms use current technologies innovatively, and where 'distributed systems' use the power of social interventions to tailor commodity exchange to local needs. Wider regional and/or global networks are created, and cultural diversity is seen as a form of 'metaculture' – a multiplicity of cultural understandings – as part of this process. The sustainable qualities that result from these alternative forms of exchange provide an increase in an 'enriched complexity' in human values, which Manzini emphasises (2015).

As these authors suggest, the 'resilient economy' of the CE is predominantly focused on the tenets of 'environment' and 'economics' and does not adequately address the third tenet for sustainable consumption, that is its 'social' dimensions. The importance of a multiplicity of *social* platforms for exchange and innovation to foster a more complex and diverse economy, capturing environmental (through efficiency) *and* social well-being is critical, and scarcely addressed in the literature on the CE. It is through deeper and multifarious consumer participation that the social complexities, diversities and values of user/consumers can provide for more resilient sustainable forms of consumption. This performative aspect of sustainable consumption is discussed further through my project, The ByeBuy! Shop, a temporary interruption to conventional consumer paradigms, established for seven days in Launceston, Tasmania, in 2014. It is offered here as an experimental lens through which the social dimensions of sustainable consumption can be more closely observed. It provided an opportunity to examine how increased social engagement, through four sustainable consumption paradigms, can influence the development of a CE.

Four Paradigms of Sustainable Consumption

The four paradigms presented here are based on consumer actions and behaviours within a retail environment. The aim was to engage shoppers to enable a more *socially* sustainable outcome, rather than to stay focused on the sustainable benefits of the consumables themselves, whether a service or a product. This provides a contrast with the present, and almost exclusive, *commodity* focus of the CE. None of the paradigms presented here demanded a singular action or behaviour but instead, contained various actions and behaviours relating to the paradigm grouping.

These four major sustainable consumer paradigms are the following:

1. Community orientated consumption
2. Ethical and political consumption
3. Product Service Systems (PSS)
4. Prosumption (Mátë, 2015)

Community-Oriented Consumption

Coupled with a sense of community, community-oriented consumption (COC) requires the incorporation of social innovation and well-being as critical contributors to a sustainable future, embracing rich and diverse communities: '…ways of living based on sharing and collaboration reinforce the transition towards sustainability: they regenerate the local social fabric and promote the creation of new common goods' (Cipolla, 2009).

COC paradigms can vary, including collaborative platforms (Botsman and Rogers, 2010; Kostakis & Bauwens, 2014; Piscicelli, Cooper, & Fisher, 2015), sharing platforms (Martin, 2015, 2016; Martin, Upham, & Budd, 2015; Price & Belk, 2016), and gifting or bartering platforms (Hyde, 2007; Piscicelli et al., 2015; Vaughan, 1997). All of these can provide a positive sense of community and well-being, and also the possibility for social innovation. 'This is the case whether the consumable is a physical product, service or virtual item, traded, loaned, shared or purchased. The value of each consuming experience is not solely based on the product or service but also on the value of the personal engagement and sense of community consumers' gain from the experience. These interactions and exchanges can occur face to face in physical environments, such as traditional places of consumption, or less traditional places such as private homes, and virtual environments such as social media, online networks and web pages' (Mátë, 2013a, p. 548). Examples of COC include farmers markets where the social connections are as, if not of greater importance, as the food and local economics (Hunt, 2007; La Trobe, 2001; Szmigin, Maddock, & Carrigan, 2003), and time banks, where time is bartered between participants, thus increasing social networks (Seyfang, 2009). COC is most closely aligned to the 'sharing platform' and 'collaborative' business model of the CE which '…facilitates the renting, sharing, swapping, lending, gifting or bartering of resources' (Lacy & Rutqvist, 2015, p. 85).

Ethical and Political Consumption

Ethical (Cherrier, 2007; Newholm & Shaw, 2007; Woodruffe-Burton, Eccles, & Elliott, 2005) and political (Jacobsen & Dulsrud, 2007; Spaargaren & Oosterveer, 2010) consumption paradigms reflect deep values and beliefs held by consumers, predominantly related to social and ecological issues. These include the consumption of fair trade, organically grown, local food and anti-consumption initiatives, which address the ethical and political issues of over consumption head-on, avoiding the consumption of goods (Mátè, 2013b).

The adoption of and adaption to the CE by the general population does not appear to require a particular ethical or political standpoint. The CE proposes that people will be adapting to their roles as a user or consumer, based on the provided systems and services, with many of the ethical/political decisions currently required to be a 'sustainable consumer' (i.e., continuing to purchase fair trade and organic food) made easier as a consequence. The prevalence of the citizen as consumer within the CE, performing their ecological and civic duties to be a 'green citizen' (Hobson & Lynch, 2016) denies the importance of the sociopolitical citizen who may challenge some of the socioenvironmental issues of the CE. De-growth through anti-consumption, for example, might disrupt the circular 'flow' of materials and their business advantage within the CE. Will such ethical opinion be stifled by the CE to maintain the conditions critical for its success?

Product Service Systems

PSS play a major role in the CE to reduce material use, where a distinction is made between the consumption and use of materials, advocating the need for a 'functional service' model, where manufacturers or retailers act as service providers, selling the use of products rather than their one-way consumption (EMF, 2013). PSS generally replace products with a service, keeping products in use for longer due to a service provider, or provide a service instead of a product for a particular function. Tukker (2004) defines PSS in three main service categories:

1. Product-oriented
2. Use-oriented
3. Result-oriented

The sustainable benefits for each type of PSS differs. Product-oriented services do not change the product, but offer disposal, take-back, and/or extended warranty options that may ensure more sustainable practices and decrease waste. Use-oriented services reduce product manufacture through reuse, and result-oriented services can radically change the system through which functions are fulfilled, resulting in more sustainable outcomes (Nawangpalupi, 2010).

PSS typically involve pay for use, leasing, renting and performance agreements (Lacy & Rutqvist, 2015) and form an important part of the CE. These PSS rely for the most part on the exchange of physical commodities, to enable the required service – even if the outcome (the service itself) is not physical, for example, Philips' Lighting as a Service (LaaS), provides light by supplying the lighting equipment the company owns (Philips, 2017). While the sharing economy in part also falls into this paradigm through commodity exchanges such as lending libraries, it does not always provide the strong sense of community one expects in the COC. Other strategies (such as those related to the Gift Economy) create PSS systems that *break* the linear material cycle. When these strategies are placed into the CE, this nonmaterial dimension offers instead values of trust and honesty.

Prosumption

An alternative to mass production, prosumption combines production and consumption, where the user or consumer produces what they consume. Coined by Toffler (1981) the definition of prosumption stretches from mass customisation to personal fabrication, co-production, distributed production (Kohtala, 2015) and bespoke production such as do-it-yourself (DIY) (Torretta & Pakbeen, 2015). The sustainable benefits of prosumption consequently vary widely and include reducing material and waste quantities, increasing re-manufacturing, reducing embodied energy, localizing production, reducing transportation, reducing product replacement and manufacturing volumes (Kohtala, 2015). Prosumption also strongly relates to the human experience of producing and consuming (Xie, Bagozzi, & Troye, 2008) including activities such as repair, refurbishing, maintaining and tinkering, where the consumer continues an active involvement with the product/service during its life cycle. This type of prosumption does not include the mass customisation of products where consumers have an input into the design of their manufactured product.

The reverse cycle or cascading effect of the CE, in particular when referring to product life-extension strategies (such as maintenance, repair and refurbishment) could include acts of prosumption. However, while the economic profitability of these acts is lauded within the CE, the value of the human experience and its benefits is absent. Through participation in creating and producing a learning process occurs, producing a deeper understanding of the commodity and creating increased value in the final 'product', and a developed understanding of the environment (Torretta & Pakbeen, 2015).

These four sustainable consumer paradigms link closely to the principles of the CE, where the actions of the user/consumer can also involve recycling, refurbishment/remanufacture, reuse/redistribution, maintenance and collection (EMF, 2013). While the material benefits of this system to a sustainable society are acknowledged, it is the human elements of the CE that have been neglected, including the users' role and value as active, creative, and engaged citizens within a diverse economy.

The ByeBuy! Shop provided a temporary interruption to conventional consumer paradigms and an opportunity to examine new paradigms of consumption and their influence within a CE system.

Concept of the ByeBuy! Shop and the Four Consumer Paradigms

The ByeBuy! Shop was contained within an existing vacant retail space and furnished using almost 100% reused or found materials and objects, with a particular focus on industrial waste found within the retail sector or related areas (see Fig. 7.1). It was open, normal retail hours and the activities of the shop were based around the four consumer paradigms discussed above. These paradigms of sustainable behaviour were enacted through four key trading interactions: Swap Shop; Story Exchange; Repair Deli and Slow Market with no financial exchange.

Swap Shop addressed the paradigms of community oriented and ethical and political consumption. It addressed the values of possessions, where objects were swapped without any monetary value (i.e., for their personal value, not their financial equality) and their histories supplied by the original owner connecting the new owner on a deeper emotional level to their trade (see Fig. 7.2).

Fig. 7.1: Street Frontage of ByeBuy! Shop.

Fig. 7.2: Swap Shop with Table Set Up for Slow Market and Repair Deli.

Story Exchange was used to address the paradigm of PSSs, by using a story to challenge the purchase of goods for emotional satisfaction (see Fig. 7.3).

Repair Deli and *Slow Market* provided new skills for repairing and making with a greater appreciation and value for the objects being repaired and/or made. They connected, therefore, with the paradigm of prosumption but also align themselves with COC. These interactions were designed to increase the value of possessions, increase social engagement and reduce consumption (see Figs. 7.4 and 7.5).

The CE and the ByeBuy! Shop

The ByeBuy! Shop provides insight into the implications of some of these issues for the 'retail face' or 'shopping scape' within a CE system, through the trading interactions of the following experimental retail 'scapes': Swap Shop, Story Exchange, Repair Deli and Slow Market.

Fig. 7.3: Story Exchange: Poetry Reading.

Fig. 7.4: Repair Deli: Bike Repair and Maintenance Session.

Swap Shop and Story Exchange – The Power of Stories

The CE requires 'users' to reduce waste and ideally, to eliminate it, through designing out waste in the manufacture of new products, enacting systems thinking and treating waste as food. The values therefore placed on future products is pragmatic: how to objectively reduce the physical impacts of the products being used. However, many products are bought through the emotional connections and values we place on objects (Crommentuijn-Marsh & Eckert, 2010; Demirbilek & Sener, 2003; Ho & Siu, 2012), affecting decisions made when purchasing products.

Fig. 7.5: Slow Market: Kite Making Session.

These emotional connections can impact on the original purchase of the product, affecting our need for it, our desire for it, and its rejection or retention at its end of life. The Swap Shop and Story Exchange activities within the ByeBuy! Shop examined how these emotional connections to objects could be interrupted.

In the Swap Shop, participants could swap any item they brought in for any other item. Unlike many other Swap Shops, there was no need for the swapped item to be of the same monetary value. The act of swapping aims to negate any net gain in ownership, reduce the waste of unwanted items and the need to purchase new items. In relation to the CE, swapping provides a pragmatic approach to reducing waste.

Participants were also asked to provide a short history of the item they wished to swap by answering six questions about the item. This strategy was inspired by research carried out by Otto von Busch's Italyan Avlusu (2003) where clothes were provided with short histories of their 'lives' before being swapped for others. This information was recorded on a card and passed on to the new owner with the item. The rationale was to connect both the original owner and the new owner with values other than need or desire. It also provided additional value to those who would more naturally participate in this activity. Through observations and remarks by the participants, these miniature histories played an important role in the experience of the Shop, the reaction to the items as objects and to the broader conceptual notions of consumption. Curiosity was invoked through the stories, with some participants more interested in the short histories than in the objects themselves. An emotional connection was formed with the item, of joy, empathy, wonder or even sadness or pity. This created an engaging 'consumer' experience prompting a curiosity beyond the item itself, supporting an epistemic dimension of curiosity, incongruity and in some cases a tactile curiosity (Máté, 2015).

These emotional connections increased each object's potential worth and extended its lifespan. The object had a story to tell, and this story could be repeated to others ad infinitum, so long as the object was kept in use. 'The stories are really emotional', said one ByeBuy! Shop participant. This was typical of the comments made, suggesting that such responsive connections place an additional subjective value on the item. As one participant of the Shop pointed out, 'The stories are sentimental. You can see the meaning behind it and makes you keen to hold onto it'. The objects were no longer inanimate objects: They were animated by the stories, which gave them purpose and a personal history, so that something hidden or unexpected was revealed. As one participant said: 'I like the story behind the objects. When you buy something in a shop it doesn't have that, it's just new and doesn't have a history behind it'; 'I like the unexpected and surprise you find in the [stories]'; 'The stories personalised it' (Máté, 2015, p. 466). The stories themselves, changing, growing, recycling with each user, may keep the objects perpetually in use, continuing to increase their value. Once the cycle of stories stops, the value of the object decreases.

Furthermore, these stories started working their magic before the items left the shop, instigating conversations between the participants themselves, or between the participants and the shopkeeper, and opening up exchanges and encounters that expanded these chance relationships. Conversations involved topics that expanded on an understanding of the object, including relationships to other objects within the shop, as well as the act of swapping and its role in reducing consumption.

While many conversations centred around strategies of reuse and recycling, connections were also made to the intangible. This was expressed by participants' comments, for example: 'We need to be able to survive if there is an environmental or economic catastrophe. The concept behind this shop will help us do this' (Máté, 2015, p. 468). This comment reflecting twenty-first century angst, reveals the fear surrounding an unpredictable future and how the ByeBuy! Shop paradigm may provide (at least in part) a solution to this. This is further reflected in another vision of the future, but with a more positive outlook: 'This is the future, this is where we are headed into the future!' (Máté, 2015). Others questioned the normative, the current status quo: 'The amount we consume is the norm, why?' (Máté, 2015).

These conversations in The ByeBuy! Shop revealed that the incorporation of stories can provide platforms for increasing commodity value, showing that making intangible connections to sustainable actions is important for the success of the CE as it gives the object a future based on its connection to something 'other'. This was made possible not only by creating the space for the stories, but by creating a space to linger and time to ponder and discuss with others. These provocations could open up a space for values of tolerance, societal concern, the protection of nature and caring, values that are linked to more sustainable behavioural practices (Thøgersen & Ölander, 2002). These behavioural practices Hobson and Lynch (2016) argue are currently missing as a critical component to the success of a CE.

Story Exchange addressed emotional attachment from a different perspective, where impulse buying or 'retail therapy' provides a positive emotional response to counteract a negative one, or fulfill a momentary desire (Atalay & Meloy, 2011; Crommentuijn-Marsh & Eckert, 2010). This type of consumption can unnecessarily increase consumption. Story Exchange provided an alternative way to meet this underlying emotional need by exchanging stories rather than products. The premise behind this concept was that the telling of a story can also provide a positive emotional response in the same way that purchasing a product does. Stories can make you laugh or cry, hold your interest, provide information, enlighten you, disgust you, and can be retold over and over again – without the need for a physical purchase. They also provide human contact, communication and social interaction.

The ByeBuy! Shop established a series of different story exchanges such as, children's book readings, adult readings, people imparting personal stories and information exchanges. Some of these were one-on-one, for example, children were read stories individually or in small groups. A physical space was created within the ByeBuy! Shop for Story Exchange that formed a relaxed atmosphere, a place where time slowed, activity was replaced with active listening and imaginations were set free.

These small interceptions were interruptions to the expectations of contemporary consumer paradigms, providing participants with an alternative to conventional consumption. They allowed for 'exchange', increasing a slowness of pace, a time to imagine or learn or both and a connection with others. Stories can be considered as gifts with no expectation of return, require no physical form, and can be given to others indefinitely.

The concept of a 'gift economy' was most notably written about by Lewis Hyde in 1979, even though gift exchange is a well-known practice in many cultures. Hyde (2007) defines a gift as something that is given without the expectation of something in return. A gift is something that can remain in circulation that can keep on being 'gifted', and can even grow through this circulation. However, when a gift is sold or exchanged, it is 'used up', and there is nothing to assure its return.

Pinchot (1995) discusses a gift economy as one that values the contributions of others, rather than just possessions; Genevieve Vaughan (2007) agrees that 'Gift giving is qualitative rather than quantitative, other-oriented rather than ego-oriented, inclusive rather than exclusive' (p. 2). It is relation building, creating community whereas the activity of exchange '…creates atomistic individuals' (p. 2). However, the implementation of a gift economy could also derail the CE by disrupting the flow of materials needed to sustain it.

These exchanges of stories within the ByeBuy! Shop provide an interruption to the material cycle. Through an increased value, commodities are taken out of the circular system for extended periods of time, reducing the 'food' required to make new products, while perhaps also negating the need for the commodity, or meeting it in a more sustainable way. Replacing the emotional need for impulse buying with storytelling takes the commodity out of the circular system completely, reducing new material needs and consequently, the requirements for reuse/recycling at end of life. These immaterial actions (gifts that continue to circulate) can provide positive material benefits to reducing environmental impacts, but may also disrupt the business model for economic growth required for the success of the CE, by disrupting the continuous input of materials required for manufacturing new products as well as the financial benefits of exchange. However, they may also provide intangible social and economic benefits, including the re-evaluation of values, challenges to accepted forms of exchange, increasing social platforms of exchange, and enhancing diverse economies and the human experience.

Slow Market – Making Time

Contemporary economies require a fast-paced environment, as the more that is manufactured and sold, the more profit is made. The CE has been established to continue this economy of growth albeit by recirculating the materials that feed it. Retail shopping reinforces this paradigm, as purchases are usually made quickly, with little interaction between the consumer and the retailer – or consideration for the materials or the time and effort used to manufacture it. The whole experience can take just minutes. The Slow Market endeavoured to slow down this whole process, asking participants to either order the making of a product for a later pick up, or to make their own in a workshop, both using found and recycled materials (ByeBuy Program, 2016). This temporal dimension (the slowing down of process within a retail environment), provided opportunities for engaged human connections, which cannot be sustained within the current economic paradigm of 'time is money' nor, it is suggested, for the success of the CE if economic growth remains a critical factor.

One of the activities within the Slow Market involved kite-making, using sticks, tape, and old newspaper. In observing a young father and son in this making process, it became clear how this activity engaged the pair. Their commitment to trying to understand how the kite was to be built meant that both father and son were learning from each other. What size sticks did they need, how would they join the sticks together, connect the paper to the timber? They also needed to engage the shopkeeper as part of this process when they became stuck in how to move forward. This was not a pre-packaged 'let's make a kite' with all the right materials and instructions at hand. Decisions and experimentation had to be made, understanding the materials and what was best to use. In the end, the kite was made, and both father and son left with a sense of achievement and anticipation to try out their new toy.

Replay this same scenario in a contemporary toyshop and a very different experience would have taken place, with very little engagement between either father and son or the shopkeeper. By slowing down the process, allowing space for activity and time for thinking and learning by making, connections were being made on numerous levels. Quality time was provided for father and son, skills were learned, involved conversations occurred between all the players, fostering values of respect and appreciation towards each other and toward the materials and skills needed to make a kite. This experience engendered emotions of happiness and pride and a sense of curiosity and achievement were provided in this brief moment of making.

Valuing time as a part of a *quality* economy rather than a *financial* economy ('time is money') provides opportunities for making connections (between human, inanimate, natural and built environments), thinking more creatively about solutions and consequential actions, taking time to create and taking responsibility for our actions. The representation of time within the CE is an important consideration to begin to separate the contemporary economies of the linear paradigm and what is proposed as the new economies of the CE. Can the CE also separate time from the economy for the environment and remain a resilient option to the current paradigm? By slowing down our actions and providing time within a CE, we provide the space to engage human and social values, over the importance of the commodity and financial cost. However, while these values may provide an important part to play in changing behaviours to support sustainable consumption, its disruption in decelerating the gain and detainment of materials into the system may not enable this 'slow movement' to find a viable place in the CE.

Repair Deli –Co-Creating Value

The act of repairing is not a new phenomenon but as our throw-away society developed, repairing items became obsolete, together with the skills involved and many specialty shops. Today, repair is a developing community practice, with places such as Repair Cafés growing annually. In 2014, it was estimated that there were over 900 Repair Cafés worldwide (Herriman, 2014). Repair and refurbishment are critical aspects of the CE to reduce the need for new or recycled materials within the closed-loop system.

The Repair Deli at the ByeBuy! Shop held a number of open and organised workshops to restore some of the skills needed for repair, providing opportunities for passing skills onto others, revaluing items and preventing them going to waste. However, the human experience and social values imparted through these acts of co-creation and repair were equally important to their potential role in the interruption of waste. It is argued here that this human element of prosumption, innovation through cocreation and the re-valuing of not only the products themselves but the human connection made through these acts, will also positively affect the uptake of the CE. Prosumption and cocreation, as well as being activities that are contained within larger remanufacturing businesses, will also be required to be integrated into smaller community scales such as within retail scapes remaining outside of the dominant CE system, potentially interrupting the cyclic system required for its economic success. Can local community-based systems such as local Repair Cafés remain viable within the CE?

Conclusion

The CE has been developed over decades of research to reduce the impacts of the commodity within a linear economic paradigm and enable a resilient future for people and the planet. Social concepts of 'sharing' and 'services' are included in the CE model as ways to redistribute commodities, lessen waste and reduce production (EMF, 2013; Lacy & Rutqvist, 2015) but not as paths to enrich cultural diversity and creativity for a resilient society (Manzini, 2015), create an economy as a diverse social space (Gibson-Graham et al., 2013) or indeed to change values and alter behaviour. The emphasis lies instead on the commodity and its economic benefits and the expectation that the 'user' will comply with these alternative forms of consumption (Hobson & Lynch, 2016). However, for the CE to succeed as a true disrupter to the current neoliberal paradigm and linear economy, a change in values to mobilise environmentally responsible or sustainable behaviour will be required (Crompton, 2013; Giacalone, Jurkiewicz, & Deckop, 2008; Hobson & Lynch, 2016; Holmes, Blackmore, Hawkins, & Wakeford, 2012; Thøgersen & Ölander, 2002; Urien & Kilbourne, 2011).

The ByeBuy! Shop aligned four major paradigms of sustainable consumption within performative retail scapes to promote and prompt discussion on alternatives to the contemporary consumer paradigm. Within this, close alignments with the principles of the CE were observed. The ByeBuy! Shop initiative provided opportunities to expand the focus of the CE from the commodity to a multiplicity of social platforms of exchange, innovation, and co-creation, revaluing human experiences and social values and the role of participants, not just as users/consumers but as sociopolitical citizens. Social economies that included intangibles such as value, emotion, gifts, time, and co-creation were consequently revealed.

Such economies require particular conditions to develop, conditions not currently observed within the contemporary linear economy, nor particularly within the CE, as these might appear to undermine its economic 'success'. The CE does much to forward the efficient use of materials and energy, creating 'closed–loop' systems to reduce the environmental impact of consumption while maintaining economic growth. Emphasis has been placed on the business and commodity aspects of the CE, avoiding the importance of the involvement of the individual, not just as a 'users' within this new paradigm who satisfy the conditions of the CE, but as critical social innovators and sociopolitical citizens, able to also develop and promote the tenets of sustainable consumption.

Retail scapes such as those presented by the ByeBuy! Shop can provide platforms where not only these social economies can be enacted, including the circular efficiencies of the commodity, but also requires the spatial conditions necessary for engaging social exchange, lingering, and co-creation. These scapes, unlike the retail shops of the linear economy, provide a place for fluid interactions, not fixed in time, space, or material elements, thus eliminating the singular condition for commodity exchange currently witnessed elsewhere. However, these social economies, disruptors to the linear economic paradigm, may also be regarded as disruptors to the CE unless their importance to the continuation of sustainable consumption is recognised. Peer-to-peer exchanges that prevent or slow the process of materials entering the CE or an increase in nonconsumption and degrowth could slow economic growth, now seen as critical to the success of the CE.

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Chapter 8

What Role for the Social Enterprises in the Circular Economy?

Ruth Lane and Wayne Gumley

Abstract

In debates about recycling and the circular economy, the role of existing organisations that already facilitate the circulation of materials through society can be neglected. Indeed, the social enterprise sector may currently be more significant than the commercial waste management sector in facilitating the circular economy within Australia. Drawing on interviews with organisations involved in collecting and reprocessing used electronics and scrap metal in Australia, the authors detail some of the synergies and tensions between the social enterprises and commercial organisations that have emerged as recycling gains traction through government policy and various forms of product stewardship. The authors conclude with suggestions for policy and governance approaches most likely to facilitate productive and perhaps symbiotic relationships between the two sectors in the future.

Keywords: Social enterprises; recycling; reuse; policy; commodity chain; circular econmy; regulation

Introduction

The idea of a circular economy as a response to unsustainable trajectories of consumption of natural resources appears to be gathering traction with a growing presence at the World Economic Forum meetings in Davos, Switzerland (Ellen MacArthur Foundation, 2014; Giurco, Littleboy, Boyle, & Fyfe, 2014). Whilst international initiatives such as the Ellen MacArthur Foundation focus on engaging product designers and manufacturers in new forms of materials efficiency, it is critical to also acknowledge and better understand already

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doi:10.1108/978-1-78714-619-820181012

existing activities that currently facilitate commodity chains leading to reuse or recycling of goods and materials (Lane & Watson, 2012, Hobson, 2015; Hobson & Lynch, 2016). These range from the practices of households, the activities of charity sector organisations and their various interfaces with commercial recycling and reprocessing industries. Because some stages of commodity chains do not involve market transactions, understanding them requires a broader definition of 'economy' – what some scholars refer to as a 'diverse economy' (Gibson-Graham, 2006) – that includes activities such as gifts and donations, voluntary labour and many aspects of government policy aimed at supporting the public good benefits of charities and not-for-profit community organisations as well as those aimed at deflecting waste from landfill. In this paper, we focus in particular on the lesser known but highly extensive role of social enterprises in the circular economy, exploring their interface with both the broader community and with markets for recycled goods and materials. Our use of the term *social enterprises* follows that of Barraket and Yousefpour (2013, p. 448), 'organisations that exist to generate a public or community benefit trade to fulfil their mission and reinvest a substantial proportion of their income in the fulfilment of their mission'.

The work reported on here forms part of the Wealth from Waste research program[1] which, in the context of global concerns around sourcing future metals and mineral needs through mining, is examining the feasibility of developing more advanced metals recycling in Australia (Corder, Golev, & Giurco, 2015; Giurco et al., 2014). The collection of used goods and materials is critical to this, and social enterprises play a significant role as an interface between the broader community in which goods and materials are redistributed and the commercial recycling industry that seeks to collect goods and materials with resale value. Whilst the passage of the National Waste Policy (Australian Government, 2009) and associated Product Stewardship Act (Commonwealth of Australia, 2011a) are encouraging developments in Australia, the policy and specific schemes initiated to date have focused primarily around the growth and expansion of a commercial recycling industry. The National Computer and Television Recycling Scheme (NTCRS), the first e-waste collection schemes to be trialled under the new legislation, has drawn information for modeling the availability of the resource of used computers and TVs from sales and import data, but has so far not included information from consumers or social enterprises, both of which are important in the commodity chain for used electronics (Commonwealth of Australia, 2011b, 2014). Significantly, the scheme is entirely focused on the collection of used equipment for destructive materials recycling in which collected products are dismantled into component materials that can then be used as feedstock for new manufacturing. It does not address the issue of repair and reuse of functional items, nor does it create any significant drivers for improvements in product design, although industrial ecologists regard these approaches as important for materials efficiency in a circular economy (Allwood, Ashby, Gutowski, & Worrell, 2011; Ghisellini et al., 2016; Kissling et al., 2013).

In this paper, we examine some social, economic and regulatory factors that influence the motivation and capacity of social enterprise organisations to undertake activities that facilitate reuse as well as recycling of goods and materials. We review different types of organisations and examine their interface with the broader community, with government agencies and policy initiatives and with the corporate sector.

Approach and Methods

Whilst our research for the Wealth from Waste research program spanned the full spectrum of organisations involved in reuse and recycling and included a wide range of commercial businesses and government agencies with various regulatory responsibilities, this paper is based on interviews conducted with 10 social enterprise organisations and a peak representative body, the National Association of Charitable Recycling Organisations (NACRO) (Table 8.1). Further information was drawn from the submissions made to the 2014 review of the National Computers and Televisions Recycling Strategy (Commonwealth of Australia, 2014).

Interviews were primarily conducted with operations managers at the site of the sorting and reprocessing facilities that they managed. Some interviews also involved visits to retail outlets. Interviews were semistructured and all except one were fully transcribed and submitted to thematic analysis using NVivo software to code for relevant themes of interest to our research and to capture issues and concerns raised by interviewees themselves. Information from both interviews and organisation websites was used to construct models of the commodity chains for used goods and materials that each organisation facilitated.

Table 8.1: List of Social Enterprise Organisations Interviewed.

Organisation	Location
The Salvation Army	National
St Vincent de Paul Society	National
The Smith Family	National
Lifeline (Brisbane)	Queensland
Computerbank	North Melbourne
Eaglehawk Eco Centre and Recycling Shop	Bendigo
Green Collect	Melbourne CBD
Outlook Environmental	Melbourne
Endeavour Foundation	Queensland, New South Wales, Victoria
Bright Sparks	Melbourne
NACRO	National (peak representative body)

Discussion of Findings

Within the social enterprise sector, a range of models exist for collection, including charity bins and drop-off centres, acceptance of donations at retail outlets, at-call collections and contracts for services to local government or business. The organisations we interviewed roughly fall into the following three groups[2]:

1. Large organisations, including church-based organisations, with extensive networks of collection and retail facilities across more than one Australian state – The Salvation Army, St Vincent de Paul Society, Lifeline (Brisbane) and the Smith Family.
2. Recycling centres connected with waste management facilities that link a primary goal of promoting employment opportunities and training with government objectives for waste diversion – Outlook Environmental, Eaglehawk Eco Centre and Recycle Shop, Endeavour Foundation.
3. Small niche recycling initiatives based on specific products or materials in an urban precinct with a mix of motives including employment training and supporting the needy as well as environmental concerns around materials recycling – Green Collect, Computerbank and Bright Sparks.

Whilst the organisations differ in terms of their role in transporting materials to central processing facilities, and in the extent to which collected goods are repaired or disassembled into component parts, we found certain elements in common across social enterprise organisations in their position in commodity chains for used goods and materials, their reliance on broad community support through donations, and in their reliance on voluntary or low-cost labour in facilitating their activities.

Role of Social Enterprises in Collection of Used Goods and Materials

Social enterprises operate the most extensive network of collection facilities for used goods and materials across Australia, including rural and regional centres as well as larger cities. The larger church-affiliated charities such as The Salvation Army and St Vincent de Paul Society are most significant in this respect, particularly for used durable goods and clothing. Most of what they collect comes in the form of donations of goods and materials from households and small businesses, motivated by both the convenient proximity of collection facilities and services as well as altruistic motives for helping the needy. In this respect, they dominate a critical stage in the commodity chain for reuse and recycling (Fig. 8.1). In 2012, the NACRO estimated 300,000 tonnes of donations were received and, of these, 38% were reused, 12% recycled locally and 10% exported for reuse or recycling (NACRO, 2013).

For goods and materials to become available for reuse or recycling, the first owners must surrender their property rights to the collecting organisation (Lane, 2011, 2014). The transfer of property rights in this context may present some

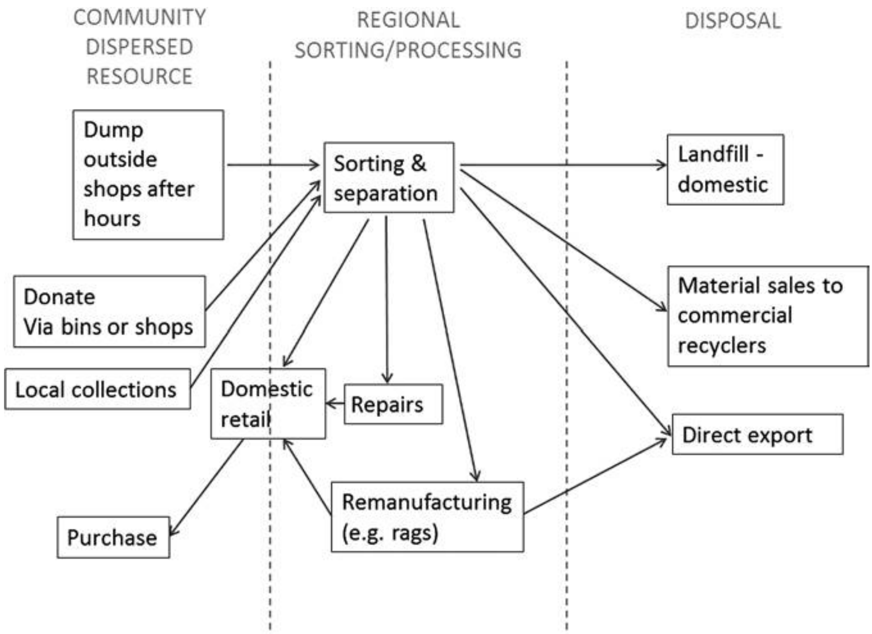

Fig. 8.1: Commodity Chain Characteristic of Large Charity Organisations with Extensive and Widely Distributed Collection and Retail Facilities.

legal difficulties. The law relating to ownership of goods or 'chattels' can be traced back to Roman times. Under the doctrine of *res derelicta,* once property was intentionally abandoned by its owner, the next person to take possession of that property became the rightful owner (Aitken, 1994). The modern practices of kerbside recycling and donations to charity through collection bins may also be interpreted as a form of *bailment*, which is the recognised legal relationship where a person voluntarily takes into custody goods which are the property of another (Lexis-Nexis, 2011). The recent advances in information technology and rapid turnover of used electronic equipment has led to an upsurge in donation of used electronic goods to social enterprises. The possibility that confidential information may be embodied in donated electronic goods, along with practices of scavenging kerbside bulky waste collections (Lane, 2011) and new social movements involving dumpster diving (Edwards & Mercer, 2012), requires significant reconsideration of these ancient property doctrines. Electronic goods containing computer memory chips (particularly computers and mobile phones) may require additional processing/digital cleansing before they can be on-sold as second-hand goods. An early MIT study found that many discarded hard drives contained information that was both confidential and recoverable (Shelat & Garfinkel, 2003). A plastic surgeon in Kansas who left a disused computer out for kerbside collection ended up being sued by several former patients whose 'before and after' photographs were found on the hard drive (Fraser, 2005). As part of our larger concern with collection systems for e-waste, the commercial e-waste recyclers we interviewed indicated that compliance with privacy and cyber-security laws is already a significant issue for them, and this is one area where social enterprises also face additional compliance obligations and potential risks of legal liability.

The redistribution and reuse of goods and materials within the community by social enterprises is generally assisted by their reputation for delivering social benefits and charitable works in the community, as well as their extensive network of collection points and retail stores. Their reputation for altruistic activities that support the disadvantaged facilitates the willingness to donate, and removes inhibitions about surrendering property in goods and materials that could retain some form of market value. Some of the representatives we interviewed emphasised the importance of 'brand reputation' to their collecting operations. The representative from The Smith Family suggested that their knowledge of the full supply chain for products sold in their stores offers a significant market niche which has the potential to be formalised in the future through a formal certification or accreditation scheme. Several interviewees from large organisations emphasised that the used clothing trade is relatively profitable and the network of collection points and retail stores established for that purpose enables them to support various other less profitable lines including electronic goods, which tend to be more labour intensive and require specialist knowledge for testing, repair and/or dismantling for material recycling. Nevertheless, used electronic goods have been an important commodity for many social enterprises and considerable expertise has been developed in this sector to facilitate socially responsible processes for handling e-waste.

One unfortunate aspect of the NTCRS introduced in 2011 is that it seems to have diverted into commercial materials recycling channels a substantial proportion of electronic goods that previously would have been suitable for repair and resale by social enterprises through their second hand store network. The background papers preceding the NTCRS clearly identified social enterprises as part of the pre-existing collection and dis-assembly channels for e-waste (Wright-Rawtec, 2010). The Decision Regulatory Impact Statement (DRIS) for the NTCRS also recognised that charities could play an important role under the scheme if they were paid or reimbursed appropriately for their efforts (Price Waterhouse Coopers, 2011, pp. 176–177). The ultimate regulatory model preferred by the DRIS based upon a 'least-cost' approach was a co-regulatory model backed by Commonwealth legislation, whereby the television and computer industries would be jointly responsible for the collection of a certain proportion of their products (Commonwealth of Australia, 2011b). Under this model, the role of social enterprises was scarcely recognised at all, as it was envisaged that the industries would enter commercial arrangements with a group of 'co-regulators' who would be driven by market forces to meet their collection and recycling targets in the most cost-effective manner. Whilst this seems consistent with one of the National Waste Policy objectives, to 'manage waste as a resource' (Commonwealth of Australia, 2009), it is commercially very naive to believe that the numerous market failures which beset the electronics industry can be remedied by what amounts in substance to a scheme of self-regulation. The outcomes of the NTCRS over its first three years of operation reveal that:

- Under 40% of the e-waste arising from those industries has been collected under the scheme.
- The scheme has fast-tracked the export of e-waste by commercial recyclers at the expense of domestic repair and reuse by social enterprises.
- Commercial operators that have participated in the scheme have fared poorly due to the need to tender for contracts in a highly uncertain trading situation – in particular they have suffered from overly optimistic estimates of material supply and resource sale values in global commodity markets.
- The data on stocks and flows of relevant electronic goods in second hand markets and at end of life disposal stage was not highly accurate (Commonwealth of Australia, 2014).

These outcomes reflect a fundamental weakness in the high-level policy mindset of the Australian Government committed to competition policy reforms. This 'small government' agenda was specifically entrenched by principles of Best Practice Regulation which require all regulatory reforms to undergo regulatory impact analysis using cost benefit analysis (Australian Government, 2014). Value for money is generally viewed as a microeconomic outcome from the perspective of a private enterprise firm. This approach inevitably places undue emphasis upon financial costs of regulation to the firm at the expense of the broader social benefits which are notoriously more difficult to assess and value. As a result, the NTCRS is making only a minimal contribution to the collection costs of e-waste whilst imposing virtually no pressure on manufacturers to engage in more effective responses such as improving the composition and design of their products, or tightening contractual arrangements with their consumers to guarantee 'take-back' of disused products.

Due to the rapidly changing applications and design of electronic products, there are numerous 'market failures' to be addressed, including a range of regulatory pitfalls as the goods in question straddle the boundary between commodities and waste. The terms of exemption from second-hand traders' legislation and licensing fees differs in every state, whilst occupational health and safety requirements and hazardous waste management rules also create significant compliance burdens. Goods and Services Tax liability could also be triggered, but in general, the sale of donated second-hand goods by a registered charity is exempt, provided there is no change in the original character of the goods (Australian Taxation Office, 2014).

The most significant challenge associated with the collection stage is that of illegal dumping, particularly outside retail stores after hours and beside charity bins located on public land, which represents a significant cost to charity organisations, especially if they are required to pay landfill fees for disposal of unwanted materials. Some organisations were engaging with police and local councils to prosecute those guilty, with the assistance of evidence recorded on security cameras. The issue of illegal dumping has been taken up by NACRO in lobbying state governments to acknowledge the likelihood of increased dumping as a side effect of the introduction or increases in the landfill levy in each state (NACRO, 2013).

A different problem exists for products and materials for which profitable markets exist, especially used clothing, where charity organisations compete with fully commercial businesses. Particular tensions have arisen with the colocation of commercial collection bins alongside those of charity organisations and, in some cases, with misleading labelling making it likely that donors will mistake them for the bins of charity organisations. The profitable trade in used clothing is largely run along commercial lines, often with professional managers drawn in from mainstream retail businesses. This is an international trade (Norris, 2012) and Australian-based charity organisations are significant exporters to buyers in Papua New Guinea and Dubai. Some organisations even import used clothing from other countries in order to maintain a constant high-flow rate for the companies they sell to. Profits from these commercial activities are used to subsidise their various noncommercial activities and programs.

A different collection model exists for social enterprises linked to waste processing facilities. In this case, donated goods and materials are brought to the facilities by donors, including builders and home renovators, who may be required to pay a gate fee for their disposal (Fig. 8.2). These recycling centres may operate on land owned or donated by local governments who also operate the associated waste transfer or landfill facility. In metropolitan Melbourne, Outlook Environmental[3] provides an example of a disability employment agency that has developed its operations in conjunction with local and state government policy and targets for waste diversion from landfill. Their labour-intensive operations model allows them to undertake a high level of disassembly of products into component materials, including different metal types, plastics, etc., which are

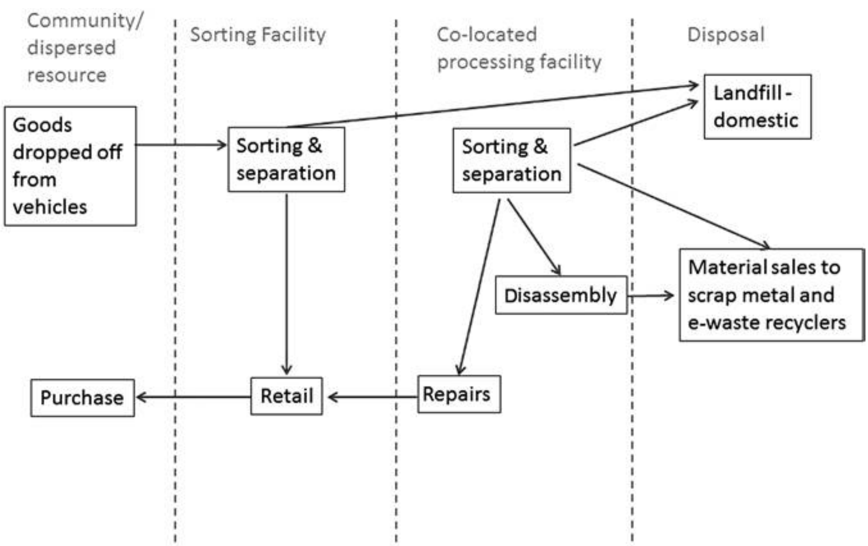

Fig. 8.2: Commodity Chain Characteristic of Recycling Centres at Waste Management Facilities.

then sold to commercial recyclers. They are now engaging with the disassembly of waste electronics, especially cathode ray tubes (CRT) from televisions and computer monitors, and have contractual arrangements with the commercial e-waste recycler, MRI E-cycle Solutions. Metals are sold to commercial bulk metal recyclers, OneSteel, SRS or Norstar depending on which offers the best price. Whilst money is made from commodity sales, more financially significant is the gate fee they are paid from the NTCRS for receiving and processing televisions, as the fee allows them to employ the staff required to undertake this work. Other funding was awarded by the Victorian Government's Metropolitan Waste Management Group for infrastructure to expand the capacity of their waste transfer centres in Melbourne to increase resource recovery. As a disability employment agency, Outlook Environmental had previously obtained government-funding assistance for employment training activities. Whilst recent changes linked to the National Disability Insurance Scheme has effectively removed this subsidy, the environmental side of the business could subsidise employment training activities if necessary. The Endeavour Foundation,[4] another disability employment social enterprise, has developed an even more diverse range of business activities, ensuring it was well buffered from changes in government policy.

A slightly different model again is found in the Eaglehawk Eco Centre and Recycle Shop in Bendigo in central Victoria, which was reformed in 2016 as the Eaglehawk Recycle Shop Inc. Originally established by the not-for-profit organisation Future Employment Opportunities, the organisation is motivated by the need for job creation and employment training for long-term unemployed in a region with very high levels of unemployment. In collaboration with the Bendigo City Council, which provided land for its operations, a facility was established adjacent to the Bendigo landfill aimed at diverting recyclable and reusable materials from landfill. The Eaglehawk Recycle Shop interacts with local businesses and the regional community to receive goods and materials that are then sorted, repaired, disassembled and sold as either used goods or bulk materials. Workers at the centre develop innovations for disassembly equipment (they designed and constructed a machine for degassing refrigerators) and for adapting used goods for sale in the retail store located on the site. Within the centre, a computer repair shop was established that sells second-hand computer equipment. Approximately, 60% of revenue comes from sales of second-hand goods and 40% from sale of materials for recycling. Any surplus is invested back into the organisation and used for new infrastructure or equipment. The Eaglehawk Recycle Shop has strong support from the regional community who visit to both drop-off unwanted goods and materials and shop for second-hand goods. The social enterprise model has now been extended to similar initiatives in other regional towns in Victoria that have developed recycle centres alongside their landfills. It also forms part of an interstate network of community recycling organisations, the Community Recycling Network Australia (CRN Australia, 2015),[5] that in turn is a member organisation of NACRO which lobbies governments on their behalf.

In addition to these larger organisations, a diverse range of small-scale organisations also play a role in the collection of more specific types of goods and materials for repair or recycling in urban precincts (Fig. 8.3). For example, in

North Melbourne, Computerbank was established in 1998 for the purpose of collecting old computers for repair and resale at low cost, and recycling non-reusable components through disassembly and sale to commercial recyclers.[6] Green Collect was formed in 2002 with start-up funding from a BP corporate social responsibility program. It is focused on collection and recycling of office materials from the Melbourne CBD as a means of creating employment and training opportunities for people from disadvantaged backgrounds through collecting discarded items for reuse, remaking and recycling.[7] Most small niche recycling organisations like these have some interaction with government funding schemes as providers of employment training programs or engaging with Work for the Dole welfare schemes. However, as these schemes fluctuate with governmental changes, their survival depends on sales of the goods and materials they collect and process.

Engagements with Government and the Corporate Sector

Whilst social enterprises are central to the circulation of used goods and commodities and do engage with the recycling of some commodities, such as reprocessing unusable textiles into saleable rags, most materials recycling is brokered by commercial businesses. Whilst there are facilities for recycling plastic, glass and paper within Australia, most metal recycling is undertaken offshore, with commercial businesses in Australia managing logistics for collection and sales to offshore buyers (Lane, Gumley & Santos, 2015). Only some of the activities involving the collection, reuse and recycling of specific products and materials are

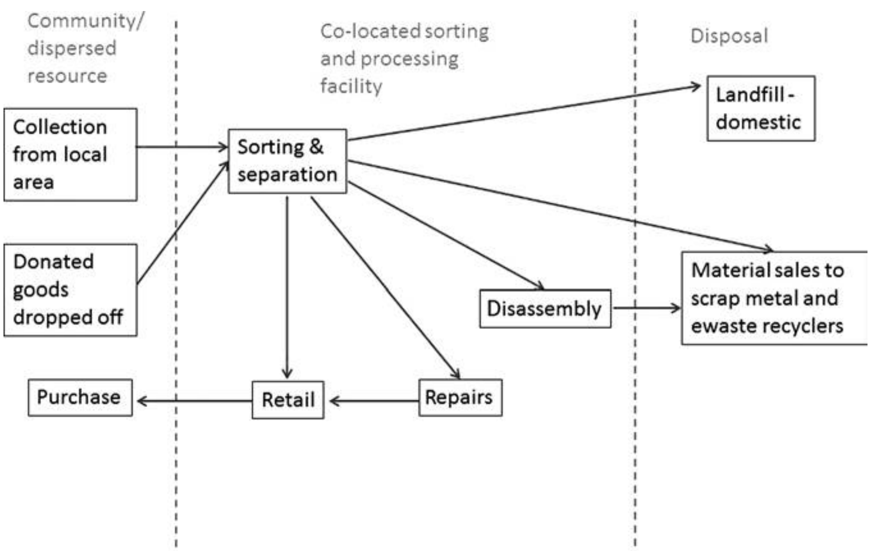

Fig. 8.3: Commodity Chain Characteristic of Small Niche Recycling Initiatives in Urban Precincts.

profitable on a commercial scale, and the largest costs involved are primarily in collection, sorting and, where undertaken, disassembly and repair work.

The introduction of the NTCRS has meant that a gate fee is now collected for depositing computers and televisions at waste transfer stations making activities at waste transfer stations more appealing to commercial businesses. In awarding contracts for managing used electronics at their transfer stations, local government authorities are obliged to follow guidelines about assessing value for money. However, this provision frequently disadvantages social enterprises compared with commercial businesses, due to the need to make an additional case around the economic value of the social benefits they bring from their employment training programs (Barraket & Yousefpour, 2013). A similar issue has been observed in Germany in relation to the awarding of local government contracts for managing waste electrical and electronic materials at transfer stations (Walther, Steinborn, Spengler, Luger, & Herrmann, 2010). Value for money provision is also easier to justify for destructive materials recycling than for repair and reuse, as the logistic costs are lower for materials destined for destructive recycling that do not need to be preserved in working order. In the Operational Review of the NTCRS (Commonwealth of Australia, 2014), respondents were asked to comment on a proposal to require reporting on engagements with social enterprises as part of the broader scheme reporting requirements. However, only some commercial organisations considered this a good idea, and social enterprises generally regarded it as a tokenistic acknowledgement of their activities in facilitating end-of-life materials recycling by commercial industry. NACRO was concerned that new product stewardship initiatives such as the NTCRS assume that the charity sector will undertake unprofitable activities, whilst the commercial sector performs profitable activities.

In government policy and legislation, there is an assumption that innovation in emerging recycling industries will be driven by the corporate sector based on profit motives. However, we found much evidence of innovation within social enterprises in the collection, sorting and disassembly/repair stages of the commodity chain. For example, workers at the Eaglehawk Eco Centre and Recycle Shop in Bendigo had designed and constructed a machine for degassing refrigerators and separating their different metal components. This was motivated by the desire to generate new employment opportunities rather than focusing on profits alone. The St Vincent de Paul Society had designed a trolley with a spring-loaded platform that reduced the risk of volunteer workers experiencing back strain. This was motivated by their desire to maintain a comfortable work environment that continued to attract volunteers. Much of the computer repair work for resale was unlikely to generate profits on a commercial scale, but nevertheless provided employment and training opportunities valued by those undertaking the work.

At the 2014 and 2015 NACRO annual conferences, there was significant discussion around the potential for charity organisations to both incorporate effective practices from the business sector, such as the strategic layout of shops, and to develop innovative partnership arrangements with commercial businesses that were mutually favorable. An existing example of a successful collaboration would be Outlook's relationship with MRI E-cycle Solutions for CRT disassembly.

An example of innovation through a charity-business relationship is Innoveq, a mobile mattress recycling plant able to be transported from one region to another to process large quantities of mattresses by separating out the metal springs to facilitate recycling and reduce landfill disposal charges. This was developed through a collaboration between the Salvation Army and an industrial engineering specialist with support from the NSW Environmental Protection Agency.[8]

Conclusion

In reviewing the role of social enterprises in an emerging circular economy, we have highlighted a number of important issues. Firstly, circular economy thinking should increase the focus on reuse and redistribution of products and materials as opposed to recycling. Whilst this issue has always been stressed by industrial ecologists (Allwood et al., 2011; Allwood & Cullen 2012), an overly market-oriented approach to a circular economy is likely to overlook such activities which may not be particularly significant in the generation of profits. This emerged as a key issue in a large study of international organisations involved in collecting IT for reuse (Kissling et al., 2013). These organisations listed the lack of regulatory requirements or incentives as the most significant barrier to their operations.

The problem is currently entrenched by the Australian Government's use of narrowly framed cost–benefit analysis in the regulatory impact analysis required for new regulated product stewardship schemes. Simplistic assumptions around economic efficiency that fail to account for environmental externalities will need to be reconsidered to support the principles of a circular economy that uses products and materials more efficiently and avoids waste (Stahel, 2013). We endorse the initiatives of some local governments to include requirements for contractors for waste transfer facilities to deliver social benefits. However, as the calculation of these can be a burden for social enterprises (Barraket & Yousefpour, 2013), support for a standard approach to this is needed.

Secondly, as social enterprises become more business-like and compete with commercial businesses, the issue of not-for-profit status is likely to become more problematic. We found very mixed responses to the new forms of competition between social enterprises and commercial businesses in the course of the research. Whilst all those interviewed acknowledged the need to become more business savvy, and some had taken significant initiatives to do so, others were concerned about the unequal leverage and resources of transnational waste management businesses, who could afford to lose money on a local government contract in order to secure market share in an emerging industry around regulated product stewardship collections.

Thirdly, more consideration is needed of the appropriate geographical scale for closing the loop in the circular economy. Social enterprises may be more significant than the commercial sector in closing the loop within the domestic economy, as they facilitate labour-intensive and low-profit activities within Australia that would otherwise be exported to low wage countries, often with lower environmental and health and safety standards (Lepawsky, Araujo, Davis, & Kahhat, 2017). In addition to co-regulated product stewardship focused on end of life material recycling, other measures may be required to support repair and maintenance of working equipment and thereby extend product lifespans. These could take the form of changes to the taxation system along the lines argued for by Stahel (2013). In 2016, Sweden introduced new measures to remove the tax burden on repair and maintenance services, and it will be important to monitor the effectiveness of such measures to assess their potential use in Australia. Other options could include the development of certification schemes for repair and reuse that ensure uniform standards for quality and labour. However, for some forms of high-end electronic equipment, it may be more realistic to form relationships with repair and refurbishment businesses in other countries in the Asia region. As with end-of-life materials recycling under the NTCRS, repair and refurbishment of items such as mobile phones and tablets could be undertaken through collaborations with appropriately certified businesses outside of Australia.

It is clear that the circular economy facilitated by the charity sector has many nonmarket dimensions and could not exist without them. These include the broad-based social support for charity organisations through donations of goods and materials, cash donations and voluntary labour. However, whilst the charity sector benefits from various forms of government policy and regulation in recognition of their public good benefits in helping the needy and in providing job training opportunities, there is not yet sufficient recognition of the importance of their non-market activities in policy initiatives to promote a circular economy through greater levels of materials recycling. The recent Federal Government product stewardship initiatives, informed by import and sales data, have focussed upon increasing the role of conventional (for profit) private enterprises, whilst ignoring the very large economy in second-hand goods facilitated by not-for-profits. As a consequence, there is a risk that new policy initiatives focused only on market-based activities could generate barriers and perverse incentives in the nonmarket parts of commodity chains that could ultimately undermine the quantities of materials able to be reused or recycled.

Notes

1. Details available at http://wealthfromwaste.net/
2. We acknowledge the existence and growing significance of online swapping and give away sites such as Freecycle or Zilch but have not yet conducted research with any of these organisations.
3. Details available at https://outlookvic.org.au/environmental/
4. Details available at https://www.endeavour.com.au/
5. Details available at http://www.communityrecycling.com.au/. Accessed on February 25, 2015.
6. Details available at http://www.computerbank.org.au/
7. Details available at http://www.greencollect.org/
8. http://innoveq.com.au/

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Chapter 9

Developing Measures for the Waste Management Hierarchy: A South Australian Case Study

Anne Sharp, Lara Stocchi, Vaughan Levitzke and Marcia Kreinhold

Abstract

The Waste Management Hierarchy is a well-established framework for conceptualizing the spectrum of desirable behaviours to manage, reduce and avoid waste. To date, research relating to the householder behaviours on the Waste Management Hierarchy has primarily focused on the lower order disposal and recycling behaviours, reflecting the areas of historical policy attention. Recently, however, policy focus has shifted to 'higher order' behaviours such as reuse and avoidance, in line with Circular Economy thinking. To address the measurement gap, this chapter develops and tests a battery of householder waste behaviour measures across the entire waste hierarchy. The battery was piloted with 573 South Australian householders, where the 'higher' order waste behaviours are more likely to be displayed as the Waste Hierarchy has been embedded in waste policy directives for many years. Findings empirically validate the Waste Management Hierarchy, deliver a quantified benchmark of the prevalence of behaviours across its spectrum and explore the underlying motives driving pro-environmental behaviour.

Keywords: Waste management hierarchy; waste behaviour; pro-environmental (green) behaviour; waste management; sustainable marketing; circular economy

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 159–175

doi:10.1108/978-1-78714-619-820181013

Introduction: Measuring Pro-Environmental or 'Green' Behaviour

Research on householders' pro-environmental behaviour has interested academia for more than 40 years, across a range of disciplines including sociology, marketing, psychology and environmental science. During this time, the approach to the conceptualisation and measurement of pro-environmental behaviour has evolved significantly. For example, researchers have gradually moved from the rather simplistic frameworks of awareness that first emerged in the 1970s (see for instance, the New Ecological Paradigm by Dunlap & Van Liere, 1978), to more elaborated psychological and economic models that were popular in the 1980s and 1990s, and then focusing on the development of pro-environmental behaviour scales in the 2000s. Additionally, pro-environmental research has moved away from single-item measures to attempts to develop multidimensional measures that capture the range of different pro-environmental behaviours at once. This is evidenced by widely cited works such as the Environmental Concern model by Stern, Kalof, Dietz, and Guagnano (1995), the model of Environmental Behaviour by Grob et al. (1995), the General Ecological Behaviour Index by Kaiser (1998) and the New Ecological Paradigm Scale by Dunlap (2000).

While making valuable contributions toward understanding and measuring pro-environmental behaviour, an underlying issue common to these works is the limited consideration placed on drivers and barriers of the measured pro-environmental behaviour. Most of these studies show inconsistent and weak correlations between individual perceptions and pro-environmental behaviour, often suggesting that specific beliefs and values pertaining to the environment might be the *outcome* rather than the source of pro-environmental behaviour (see for example, Dahlstrand & Biel, 1997; Karp, 1996; Schlegelmilch, Bohlen & Diamantopolous, 1996; Schulz & Zelezny, 1999; Stern, 1999; Stern et al. 1995). For example, a study of 21 countries found that environmental concerns seldom explain more than 10% of the variance in general green behaviour (Wright & Klÿn, 1998). The widely acknowledged lack of consistency between the majority of consumers' expressed concerns about sustainability issues and their actual willingness to reflect those concerns in their behaviours (Wright & Klÿn, 1998) is referred to in the literature as the Attitude–Behaviour Gap (Carrigan & Attalla, 2001). This is not to suggest that consumers place little importance on the environment, but that the average consumer makes many of their behaviour decisions quickly and without much evaluation. This explains why many brands that make strong environmental claims are characterised by low market share and a poor correlation between attitudes and actual in-store pro-environmental brand behaviour (Gupta & Ogden, 2009; Wright & Klÿn, 1998). It appears that good intentions do not always translate into purchasing behaviour.

Because pro-environmental behaviour research has sat across so many disciplines, there is the added issue of disparate measurement and methods used which has hampered the comparability of research findings and extent of replication. This has led to academic findings not being known about or leveraged to the full extent by policy-makers in the environmental area.

One area where there is such a noted void between academic research and government waste policies is the Waste Management Hierarchy. This hierarchy, established in the mid-1970s, was introduced by the European Commission Directive 75/442/EEC in 2006 as part of the Waste Framework Directive. This directive sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling and recovery. It also states that the waste legislation and policy of the EU Member States need to apply as a priority under the Waste Management Hierarchy (European Commission, 2015a). The hierarchy is structured with prevention (via avoidance and reduction) at the top, then reuse, recycling, recovery, treatment and disposal. In this hierarchy, prevention of waste is denoted as the most preferred goal for policy initiatives. This is because prevention usually results in the least environmental and economic life cycle costs as no collecting or processing of materials is required. The reuse of waste is the next most desirable policy focus. Reuse does not require any structural changes to the material and although it requires collection, it needs little to no processing. The recovery of waste encompasses both recovery of materials and recovery of energy – whichever of these two options is better for the environment and human health. Finally, disposal is the least preferable policy option, only considered once all other possibilities have been explored.

The framework is now recognised internationally as an aspirational framework for sustainability (Zero Waste SA, 2011) and a guide for prioritizing waste management practices across nations. Unlike the many scales and measures of pro-environmental behaviour found in academic research, this framework postulates a certain hierarchy of pro-environmental behaviour and assumes that the policy can act upon driving such behaviours and the progression from low-to-high order behaviours in the hierarchy. With the increasing formal articulation of waste strategies by countries, this hierarchy has been commonly used as a means to prioritise policy initiatives in the UK, USA and Australia.

To date, the majority of policy efforts and program deliveries have been focused on lower-order behaviours such as lifting landfill diversion rates through infrastructure improvements including introducing high-performing, consistent kerbside household recycling systems. Yet with increasing interest in the concepts of a Circular Economy and Cradle-to-Cradle thinking, there is a need to look beyond the easy wins of reuse and disposal to the higher-order avoidance behaviours. This is now being reflected in policy and agency focus with agencies such as the UK's progressive WRAP agency rebranding as 'Circular Economy and resource efficiency experts'. Additional evidence of this shifting focus comes from the 2008 Waste Framework Directive which requires that EU Member States shall establish Waste Prevention Programs not later than 12 December 2013 under Article 29 (European Commission, 2015b).

Few existing approaches to measuring householders' pro-environmental behaviour offered in academic research have been mapped against this Waste Management Hierarchy. Work by Barr, Gilg, and Ford (2001) was the first notable effort in the area and their paper called for research to better reflect in academia the prominence given to the higher-order waste behaviours amongst households by government. They also noted the need to describe the level of each behaviour in comparison with other behaviours and the extent to which these differ not merely in the population as a whole, but within population groups. They hypothesised that finding differences in the incidence of behaviours across the hierarchy would suggest there are different antecedent drivers of such behaviour and this needs to be established before policy-makers can tackle the range of waste hierarchy behaviours. Their work, built largely on North American literature, extended the findings to the UK. The present research takes a similar approach, describing the extent of pro-environmental behaviours across the Waste Management Hierarchy, but validating the UK and US literature in an Australian content. This is the first known such published effort. Additionally, this research examines respondents' perceived drivers and barriers to pro-environmental behaviour to reveal the strongest and weakest factors motivating them to undertake pro-environmental behaviour across the Waste Management Hierarchy.

Methods

The research was undertaken in South Australia which is the leading state for householder waste management initiatives in Australia, being the first to introduce container deposit legislation, standardise kerbside bin systems across councils and ban single-use plastic bags from retail grocery outlets. This state was chosen because its environmental leadership provided the greatest chance for the 'higher' order behaviours to be displayed.

To develop robust measures for the range of pro-environmental behaviours that could be explicitly linked to the Waste Management Hierarchy, a phase of desktop research of both academic and industry published literature was undertaken, to review prior efforts of conceptualizing and measuring pro-environmental behaviour. This was conducted by two of the authors who are experienced in literature reviews in their academic roles. Key search words linked to the Waste Hierarchy were used and a wide range of disciplines covered including marketing, social and environmental psychology and health disciplines as well as (grey) industry literature. Eighteen key articles were identified in this literature review process as being relevant (from their keywords and/or titles) and having potential measures that could be adopted for the new battery of key behaviours.

From this review, a questionnaire was developed to cover the range of behaviours previously identified. Quantitative telephone interviews were conducted with 573 randomly selected householders from metropolitan and regional South Australia. All interviews were conducted using quality accredited interviewers. Respondents were asked whether they had previously undertaken a series of pro-environmental behaviours in the past year (Yes/No questions). The pro-environmental behaviours tested in this research were grouped into two broad categories developed to reflect the Waste Management Hierarchy. These were the following:

Compliance Behaviours: used to group questions about those behaviours that householders may undertake to reduce environmental impact but for which there are generally developed infrastructures or incentives. These reflect the lower order of the Waste Hierarchy of dispose, treatment, recover and recycle. The specific behaviours measured were the following: saving water/energy; collecting bottles/cans and returning to depot; recycling electronic (which is banned from landfill in the state); recycling light globes; installing water tanks; switching to a green energy provider; installing solar panels; using a compost bin/worm farm for kitchen scraps; regularly making a shopping list prior to shopping; regularly checking the fridge and pantry before going shopping and regularly taking own shopping bags to the grocery store (there is a ban on single use bags in the state). Creating shopping lists and checking the pantry were behaviours that had been linked to minimizing food waste in prior research (WRAP (UK), 2014).

Thoughtful Consumption Behaviours: used to describe behaviours that required more individual effort and reflect the higher order of the Waste Management Hierarchy. These include purchasing environmentally friendly products, purchasing a specific brand because it came in a reusable or refillable pack or container; reducing the use of a car; donating to charity; swapping with friends/family; buying or selling through garage sales; buying or accepting second-hand clothes; buying or accepting through online sites such as Gumtree, Ebay or Freecycle; buying second-hand furniture; taking something from a kerbside hard waste collection (these are items too large to be disposed of via the kerbside bin system such as bicycles or furniture); using online or social networks (outside family/friends) to borrow infrequently used items; considering carbon emissions/footprint when making travel plans and repairing something. These equate to the reuse, reduce and avoid levels of the Waste Management Hierarchy.

As found in the desktop research phase of this project, responses gathered with this approach can be used to develop objective measures of pro-environmental behaviour at an aggregate level (i.e., across all householders), by calculating benchmarks of: (i) which behaviours are more and less established (estimated from the actual proportion of respondents claiming to have undertaken a behaviour, treated as a probability measure); (ii) which behaviours provide a more robust description of the overall engagement in pro-environmental behaviour across the population and (iii) the likelihood of future recurrence of such behaviour (estimated through one-way ANOVAs and the analysis of correlation coefficients).

Furthermore, using Mean Absolute Deviations (MAD) (see Kennedy & Ehrenberg, 2001, for further details), we examined the above benchmarks to see if there were discernible segments of consumers who tended to undertake some behaviours, or groups of behaviours, more than others. Specifically, meaningful differences in the behaviours were looked for by: (i) demographics – for example, in terms of age group or living in metro or regional areas; (ii) holding specific perceptions or attitudes in relation to environmental issues and (iii) holding specific self-beliefs, such as holding the self-perception of being seen as a 'greenie' by others. To do this, segments were identified using demographics, perceptions or self-beliefs and then differences in the behaviours of the members of those groups were compared against the whole sample. In this way, we could determine if these segments were in fact significantly different in terms of their environmental behaviours. In line with previous research (Kennedy & Ehrenberg, 2001), we used a cut-off value of MAD scores greater than 10% variation from the whole sample average as an indication of meaningful differences. When doing so, we controlled for uneven subsample sizes by weighting the MAD scores by the percentage of the whole sample represented by each subsample.

Finally, this research explored the possible underlying motives driving pro-environmental behaviour, as perceived by the householders. Specifically, we identify the perceived most and least relevant drivers of pro-environmental behaviour, as seen by the householder, choosing from a list of 10 potential factors identified in prior literature that may motivate or influence their decision to undertake such behaviours. All potential factors considered were randomised in the order they were shown to respondents and different subsets of factors were prompted to each respondent, to avoid survey-order bias. The responses were gathered in a way that mirrored the research design of a Best–Worst choice experiment, which is commonly used in consumer research to uncover drivers of consumer decisions (Marley & Louviere, 2005). For each of the drivers examined we then calculated a score derived from the ratio between two values, namely: (i) the difference between the count of respondents identifying that factor as most relevant and the count of respondents identifying it the least relevant driver of pro-environmental behaviour and (ii) the number of times that particular driver was randomly prompted to respondents, multiplied by the total number of respondents in the survey. We inspected the scores calculated with this method across all drivers of pro-environmental behaviour considered, in order to identify the strongest (highest-positive score) and the weakest (highest-negative score) drivers. When doing so, we ensured that the patterns emerging in the scores were consistent across all respondents by examining deviations from the mean responses given for each driver considered (carried out with linear regression and the analysis of the sum of standard square errors). The inclusion of this additional step of analysis provides a more comprehensive measurement of pro-environmental behaviour through supplementing the indication of how established and how likely to recur pro-environmental behaviour is, with insights into the strongest and weakest underpinning motives for undertaking the behaviours at all.

Results and Discussion

Incidence of Behaviours in the Last Year

As might be expected, given the historical government policy emphasis, compliance behaviours were generally more established (i.e., occurred across a greater number of respondents) than thoughtful consumption behaviours. As shown in Table 9.1, the most established behaviours were conserving water and energy, and using 'green' shopping bags, with 98% and 95% of householders claiming to have undertaken these behaviours in the past year. Given there had been water restrictions imposed on the state and a ban on single-use plastic bags being given for free by retailers, such high figures are not surprising. The least established (lowest incidence) compliance behaviours were the use and installation of alternative sources of energy and the recycling of light globes. Only 23% of respondents

Table 9.1: Incidence of Compliance Behaviours.

Behaviours	**Yes**	**No**
Deliberately tried to conserve water and energy use in your home	97%	3%
Consistently taken your own bags shopping rather than buying store bags	95%	5%
Regularly checked your fridge and pantry before going shopping	88%	12%
Regularly made a shopping list prior to shopping	88%	12%
Collected bottles and cans and returned them to a depot to collect the money	87%	13%
Recycled your electronic waste	77%	23%
Used a compost bin/worm farm or collected kitchen scraps rather than putting them in the rubbish	64%	36%
Installed water tanks in your home	63%	32%
Switched to a green energy provider	42%	56%
Installed solar panels	35%	60%
Recycled used light globes through the Back Light service run through some hardware stores	23%	77%
Average incidence	69%	31%

claimed to have recycled light globes in the last year. These are areas that have had less infrastructure investment. Overall, across the battery of 11 compliance behaviours, there was 69% participation in at least one or more behaviour across the respondents.

In the past year, half of the householders interviewed had undertaken at least one thoughtful consumption behaviour. In particular, as shown in Table 9.2, the most established behaviours were donating, swapping, reusing and consumption choices in general. For example, donating to charity was a behaviour 90% of respondents claimed to have undertaken in the last year. Thoughtful consumption behaviours linked with using, buying or purchasing or accepting second-hand goods occurred relatively less frequently, all receiving under 30% claimed occurrence each.

Donation was the most frequent thoughtful consumption behaviour, and the most common way of disposing of goods no longer wanted was through donating them, followed by purchasing environmentally friendly products. Repairing was also a quite common pro-environmental behaviour at 69% claimed occurrence in the last year.

Table 9.2: Incidence of Thoughtful Consumption Behaviours.

Behaviours	**Yes**	**No**
Disposed of your unwanted possessions through donating them to charity	90%	10%
Deliberately chosen to purchase an environmentally friendly product	77%	23%
Had something repaired so you did not have to buy a new one	69%	31%
Swapped unwanted possessions with family and friends	66%	34%
Bought or accepted clothing that was second hand	57%	43%
Deliberately purchased one brand because it came in a reusable or refillable pack or container	55%	45%
Reduced your use of a car through choosing to take public transport, walking, cycling or car-pooling	51%	49%
Bought or sold items through an online site such as Gumtree, eBay or Freecycle	36%	64%
Bought or sold something through a garage sale	35%	65%
Considered carbon emissions and your carbon footprint when making travel plans	30%	70%
Bought second-hand furniture	28%	72%
Taken something from a curbside hard waste collection that you thought would be useful to you	19%	81%
Used online or social networks (outside of friends/ family) to borrow infrequently used items	17%	83%
Average incidence	49%	51%

Variations in Rank or Incidence of Behaviours by Demographics and Attitudes

To investigate if there was a requirement for policy and interventions to tailor to different segments (e.g., across different age brackets, gender or for regional householders), the rank order of occurrence and the proportion of householders undertaking each pro-environmental behaviour was examined across the various demographic groups. The segment statistics were then compared against norms for the entire group of surveyed respondents and the difference in either rank order of behaviours or claimed incidence were noted. In interpreting the tables, the numbers show the percentage points difference between the profile for the demographically specified group (i.e., sub-segment) against that of the whole sample of respondents. Tables 9.3 and 9.4 show an example of the analysis conducted by age groupings. The clear out take from Tables 9.3 and 9.4 is that there is

Table 9.3: Comparison at Segment Level (Demographics) – Compliance Behaviours (Showing Weighted MAD Scores in the Incidence of These Behaviours vs the Whole Sample).

Behaviours	**18–24**	**25–34**	**35–44**	**45–54**	**55–64**	**65+**	**Metr.**	**Reg.**
Deliberately tried to conserve water and energy use in your home	0%	0%	0%	0%	0%	0%	1%	1%
Consistently taken your own bags shopping rather than buying store bags	0%	0%	1%	0%	1%	1%	0%	0%
Regularly checked your fridge and pantry before going shopping	0%	0%	1%	1%	0%	2%	1%	1%
Regularly made a shopping list prior to shopping	0%	0%	0%	1%	0%	0%	1%	1%
Collected bottles and cans and returned them to a depot to collect the money	0%	0%	0%	0%	1%	0%	1%	1%
Recycled your electronic waste	0%	1%	1%	0%	3%	0%	2%	2%
Used a compost bin/worm farm or collected kitchen scraps rather than putting them in the rubbish	0%	0%	0%	1%	1%	1%	2%	2%
Installed water tanks in your home	0%	1%	0%	0%	1%	1%	5%	5%
Switched to a green energy provider	0%	0%	1%	1%	1%	2%	1%	1%
Installed solar panels	0%	1%	1%	0%	2%	0%	1%	1%
Recycled used light globes through the Back Light service run through some hardware stores	0%	1%	1%	1%	1%	2%	0%	0%

Table 9.4: Comparison at Segment Level (Demographics) – Thoughtful Consumption Behaviours (Showing Weighted MAD Scores in the Incidence of These Behaviours vs the Whole Sample).

Behaviours	**18–24**	**25–34**	**35–44**	**45–54**	**55–64**	**65+**	**Metr.**	**Reg.**
Disposed of your unwanted possessions through donating them to charity	0%	0%	0%	1%	1%	2%	0%	0%
Deliberately chosen to purchase an environmentally friendly product	0%	0%	0%	2%	1%	3%	1%	1%
Had something repaired so you didn't have to buy a new one	0%	0%	3%	2%	1%	4%	0%	0%
Swapped unwanted possessions with family and friends	0%	0%	1%	2%	1%	3%	1%	1%
Bought or accepted clothing that was second hand	0%	1%	1%	1%	2%	2%	1%	1%
Deliberately purchased one brand because it came in a reusable or refillable pack or container	0%	0%	1%	2%	2%	5%	1%	1%
Reduced your use of a car through choosing to take public transport, walking, cycling or car-pooling	0%	0%	0%	1%	1%	2%	3%	3%
Bought or sold items through an online site such as Gumtree, eBay or Freecycle	0%	2%	3%	4%	0%	9%	1%	1%
Bought or sold something through a garage sale	0%	1%	3%	1%	0%	3%	3%	3%
Considered carbon emissions and your carbon footprint when making travel plans	0%	0%	0%	1%	0%	2%	1%	1%
Bought second-hand furniture	0%	1%	2%	2%	0%	4%	0%	0%
Taken something from a curbside hard waste collection that you thought would be useful to you	0%	1%	1%	0%	0%	2%	4%	4%
Used online or social networks (outside of friends/family) to borrow infrequently used items	1%	1%	2%	0%	1%	3%	3%	3%

very little difference in environmental behaviours by different age of the respondent, as evidenced by the high number of '0s' in the tables.

As Tables 9.3 and 9.4 show, once subsample sizes are accounted for, the analysis did not identify any meaningful differences across these demographics that would mean program tailoring was required. That is, the average difference in absolute value of the incidence of all compliance and thoughtful consumption behaviours for the various segments vis-à-vis for the whole sample was always considerably small, that is, less than 10% and generally smaller than 5%.

This is a positive, but surprising finding. There are no groups of individuals whose behaviour varies significantly from others in the population, even if they may differ in demographic terms, such as age in Tables 9.3 and 9.4. The implication is that any marketing action related to maintaining or increasing the level of establishment of pro-environmental (green) behaviour can be undifferentiated across all demographic groups, thus making communication efforts a much less challenging task and related investments in such efforts scalable.

Even clearer results in relation to this matter were obtained when looking at respondents holding specific perceptions and attitudes (see Tables 9.5 and 9.6) and their participation in the various behaviours. Again, differences between the various segments holding different perceptions and the overall sample were always smaller than 5%, even in relation to crucial perceptions such as the respondent's assessment of the importance of their recycling efforts and their self-perception of being seen as 'greenie' and knowledgeable in terms of recycling and environmental matters. Tables 9.5 and 9.6 show the results for respondents across six attitudinal grouping for their level of agreement with statements about recycling, littering, illegal dumping, their belief in the extent of the environmental problem, the extent of their personal disposal and also how green others perceive them to be.

In line with the above, it can be concluded that, even though people vary demographically and in terms of how they feel about waste issues, there is a striking commonality across the Waste Hierarchy behaviours they actually undertake in their everyday life.

Predicting Pro-Environmental Behaviours

When considered at an aggregate level as an overall measure of pro-environmental behaviour, the incidence of Thoughtful Consumption Behaviours provided a more reliable indicator of future likely pro-environmental behaviour than the incidence of Compliance Behaviours. That is, although slightly less established across householders (i.e., lower levels of claimed occurrence of these behaviours), Thoughtful Consumption Behaviours provided a more accurate indication of the likelihood of future occurrence of pro-environmental behaviour within the sample considered.

This was established by examining the values of Cronbach's alpha and via regression models to determine the extent to which the individual behaviours within each battery (i.e., Thoughtful Consumption and Compliance Behaviours) explained the variation in the underlying likelihood to undertake any

Table 9.5: Comparison at Segment Level (Attitudes) – Compliance Behaviours (Showing Weighted MAD Scores in the Incidence of these Behaviours vs the Whole Sample).

Deliberately Tried to Conserve Water and Energy Use in your Home	**0%**	**0%**	**0%**	**0%**	**1%**	**0%**
Consistently taken your own bags shopping rather than buying store bags	1%	1%	1%	1%	1%	0%
Regularly checked your fridge and pantry before going shopping	0%	0%	1%	0%	0%	1%
Regularly made a shopping list prior to shopping	0%	0%	0%	0%	0%	0%
Collected bottles and cans and returned them to a depot to collect the money	1%	0%	0%	0%	0%	0%
Recycled your electronic waste	0%	0%	1%	0%	1%	1%
Used a compost bin/worm farm or collected kitchen scraps rather than putting them in the rubbish	1%	1%	1%	1%	5%	4%
Installed water tanks in your home	2%	2%	1%	1%	2%	3%
Switched to a green energy provider	0%	1%	1%	2%	2%	2%
Installed solar panels	0%	0%	0%	0%	0%	0%
Recycled used light globes through the Back Light service run through some hardware stores	1%	0%	1%	0%	0%	4%

Notes:

- Att1 = Attitude 1 – Agreed with 'I feel like my recycling efforts are worthwhile'.
- Att2 = Attitude 2 – Agreed with 'Littering is a problem in my area'.
- Att3 = Attitude 3 – Agreed with 'Illegal dumping is a problem in my area'.
- Att4 = Attitude 4 – Agreed with 'A lot of threats to the environment are exaggerated'.
- Att5 = Attitude 5 – Agreed with 'It is important to me to reduce the number of unwanted items that I eventually have to throw away'.
- Att6 = Attitude 6 – Agreed with 'Other people see me as a bit of a "greenie" when it comes to shopping, recycling and disposing of things'.

Table 9.6: Comparison at Segment Level (Attitudes) – Thoughtful Consumption Behaviours (Showing Weighted MAD Scores in the Incidence of these Behaviours vs the Whole Sample).

Behaviours	**Att1**	**Att2**	**Att3**	**Att4**	**Att5**	**Att6**
Disposed of your unwanted possessions through donating them to charity	1%	0%	0%	1%	1%	1%
Deliberately chosen to purchase an environmentally friendly product	2%	1%	1%	1%	5%	3%
Had something repaired so you didn't have to buy a new one	1%	0%	0%	0%	0%	1%
Swapped unwanted possessions with family and friends	1%	0%	1%	1%	1%	2%
Bought or accepted clothing that was second hand	1%	1%	2%	2%	2%	4%
Deliberately purchased one brand because it came in a reusable or refillable pack or container	1%	1%	1%	1%	3%	3%
Reduced your use of a car through choosing to take public transport, walking, cycling or car-pooling	1%	1%	0%	1%	2%	3%
Bought or sold items through an online site such as Gumtree, eBay or Freecycle	0%	0%	1%	1%	0%	3%
Bought or sold something through a garage sale	0%	0%	1%	0%	1%	2%
Considered carbon emissions and your carbon footprint when making travel plans	1%	0%	2%	1%	2%	3%
Bought second-hand furniture	0%	0%	1%	1%	1%	3%
Taken something from a curbside hard waste collection that you thought would be useful to you	0%	1%	1%	1%	0%	2%
Used online or social networks (outside of friends/family) to borrow infrequently used items	0%	0%	0%	1%	1%	1%

Notes:

- Att1 = Attitude 1 – Agreed with 'I feel like my recycling efforts are worthwhile'.
- Att2 = Attitude 2 – Agreed with 'Littering is a problem in my area'.
- Att3 = Attitude 3 – Agreed with 'Illegal dumping is a problem in my area'.
- Att4 = Attitude 4 – Agreed with 'A lot of threats to the environment are exaggerated'.
- Att5 = Attitude 5 – Agreed with 'It is important to me to reduce the number of unwanted items that I eventually have to throw away'.
- Att6 = Attitude 6 – Agreed with 'Other people see me as a bit of a "greenie" when it comes to shopping, recycling and disposing of things'.

pro-environmental behaviour. The Thoughtful Consumption behaviours yielded a Cronbach's alpha value of 0.7 and displayed only a few weak correlations between the questions (smaller than 0.2 when significant) as well as significantly different mean scores, and explained 52% of the variance in the overall level of engagement in pro-environmental behaviour [F (572,12) = 1592.49, $p < 0.00$].

In comparison, Compliance Behaviours also showed only small and weak correlations (<0.2 if significant and only in two instances equal to 0.3 for the items 'checking the pantry before shopping' and 'making a shopping list') and significantly different mean scores; yet, they yielded a lower Cronbach's alpha value (0.44) and explained a mere 30% of the variance in the overall level of engagement in pro-environmental behaviour [F (572,10) = 1762.53, $p < 0.00$].

Hence, although it can be concluded that both batteries of behaviours can be used as robust measures of the likelihood to undertake pro-environmental behaviour, Compliance Behaviours are a somewhat less reliable indicator of the likelihood of consumers to engage in pro-environmental behaviour in the future than Thoughtful Consumption Behaviours.

To confirm this finding, we repeated the analysis merging the two batteries being treated as one overall one, rather than split. We obtained a Cronbach's alpha value of 0.66, which is the exact same value obtained when just using the Thoughtful Consumption battery. All behaviours showed only small and weak correlations (all < 0.2 if significant) and significantly different mean scores, explaining a total of 53% of the variance, that is, just 1% more than when considering only Thoughtful Consumption behaviours alone [F (572,23) = 3719.62, $p < 0.00$]. The outcome of this additional empirical check confirms the importance of considering Thoughtful Consumption and therefore the higher-order Waste Management Hierarchy behaviours when seeking to measure, understand and plan for future waste management in a population. It is the dimensions of these behaviours that are more reliable indicators of the populations' likelihood to continue to engage in these behaviours in the future.

Drivers of Pro-Environmental Behaviour

For the perceived drivers of pro-environmental behaviour, respondents indicated as the most influential factor the fact that such behaviours would be beneficial to the environment (i.e., perceptions of a clear link to results). This was followed, in the order, by other factors such as 'Habit', 'Making a difference', 'Knowing the impact of one's actions' and 'Understanding climate change'. By contrast, respondents indicated as the least influential driver the amount of effort required and the influence of others, respectively. This pattern is illustrated in Table 9.7, which report the Best–Worst scores obtained for each of the various drivers of pro-environmental behaviour prompted in the survey.

Importantly, the scores were underpinned by a homogenous population view, that is, the 'most' and 'least' influential factors were consistent across all respondents, as indicated by the outcome of a linear regression analysis (R2 of 0.95). So it is not the case that potential barriers and their relative importance vary amongst different types of respondents. This is shown in Table 9.7.

Table 9.7: Strongest and Weakest Drivers Of Pro-Environmental Behaviour.

Factors Influencing Taking Up Green Behaviours…	Best Worst Score
It's beneficial to the environment	0.11
Habit – just being used to doing it growing up with it	0.05
Makes me feel socially responsible – I make a difference	0.04
Receiving info on the environmental impact of my actions	0.04
Having an understanding of climate change issues	0.03
It's a way to save money	0.00
My children and what they learn and bring home	−0.02
Having time to do it – when I'm not too busy	−0.04
It doesn't require too much effort – if it's easy I'll do it	−0.07
Other people's influence on me to behave that way	−0.12

Conclusions and Implications

A number of important conclusions come from these findings. Firstly, this research has validated and benchmarked the range of Waste Management Hierarchy behaviours amongst South Australian respondents. This is the first time the Hierarchy has been used in Southern Hemisphere research. This extends the range of conditions and respondents under which this framework is seen to hold. We see the range of behaviours across the spectrum being currently displayed by respondents, with the expected higher adoption of the lower-order behaviours.

Interestingly, the incidence of these behaviours does not vary significantly by user group whether they are formed by demographics, attitudes to the environment or self-perceptions of how they are performing on environmental behaviours. This is a very positive finding as it means that any party wishing to communicate on environmental issues to the general population has a relatively homogenous audience, and so consequently messages do not need to be tailored and the messages potentially diluted.

The results also provide clear direction for waste management priorities by highlighting which pro-environmental behaviours are well-established across householders and which ones are not; and they also identify which pro-environmental behaviours (if undertaken) are more likely to indicate future occurrence at the aggregate level. As such, this work has strengthened a much-needed link between government policies and infrastructure and academic research in relation to the conceptualisation and measurement of pro-environmental behaviour and where policy formulation and infrastructure investment can have the most impact.

This research also illustrates how to establish explicit links between objective measurement of pro-environmental behaviours amongst a population and tactical tools used for policy-making, such as the Waste Management Hierarchy. The research illustrates that by measuring the Waste Management Hierarchy it is possible to both monitor and benchmark the level of establishment of pro-environmental behaviours across the framework, and to also track the effectiveness of policies in reinforcing established behaviours and nudging less established ones.

Finally, by identifying the key perceived drivers of pro-environmental behaviour, we provide a clear path to design informed policies tapping into the strongest drivers of pro-environmental behaviour – increasing awareness of the environmental benefits and aiming at turning pro-environmental behaviour into current householders' habits. Interestingly, it is not perceptions of the effort or time required that is most motivating to people, or the influence of others that are perceived by respondents to be the key motivators to behaviour change. This is again a positive finding for environmental communicators.

Overall, this research positively contributes to building a deeper understanding of pro-environmental behaviours across householders and how the Waste Management Hierarchy can be a useful lens through which to examine these behaviours. That there is so much commonality in behaviours and perceived motivators to undertake pro-environmental behaviours across people who differ substantially in their demographic profile and values and attitudes is a possible message for being able to develop programs and targets that are scalable and will hold mass appeal.

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Part III

Waste and Resource Recovery

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Chapter 10

Australian Regional Waste Footprints*

Jacob Fry, Manfred Lenzen, Damien Giurco and Stefan Pauliuk

Abstract

The production of waste creates both direct and indirect environmental impacts. A range of strategies are available to reduce the generation of waste by industry and households, and to select waste treatment approaches that minimise environmental harm. However, evaluating these strategies requires reliable and detailed data on waste production and treatment. Unfortunately, published Australian waste data are typically highly aggregated, published by a variety of entities in different formats and do not form a complete time-series. We demonstrate a technique for constructing a multi-regional waste supply-use (MRWSU) framework for Australia using information from numerous waste data sources. This is the first subnational waste input–output framework to be constructed for Australia. We construct the framework using the Industrial Ecology Virtual Laboratory (IELab), a cloud-hosted computational platform for building Australian multiregional input–output tables. The structure of the framework complies with the System of Environmental-Economic Accounting (SEEA). We demonstrate the use of the MRWSU framework by calculating waste 'footprints' that enumerate the full domestic supply chain waste production for Australian consumers.

Keywords: Input–output; waste; environmental foot-printing; consumption; regional analysis; environmental-economic accounting

*This chapter is a summary of an article published in the *Journal of Industrial Ecology*: Fry, J., Lenzen, M., Giurco, D., & Pauliuk, S., (2015). An Australian multi-regional waste supply-use framework. *Journal of Industrial Ecology*. doi:10.1111/jiec.12376 Published here with permission.

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 179–190

doi:10.1108/978-1-78714-619-820181015

Introduction

Solid waste production in Australia has been increasing in recent decades, as it has in other OECD nations (ABS, 2013b; Hoornweg & Bhada-Tata, 2012; Hyder Consulting, 2012a), and is associated with growing population, affluence and material consumption (Hoornweg, Bhada-Tata, & Kennedy, 2014). Industry produces waste during production as raw materials are transformed into products, with waste as a 'by-product' (Baumgärtner, Dyckhoff, Faber, Proops, & Schiller, 2001). Consumers and households generate waste when the products they purchase are no longer useful or have a low perceived value because of, for example, convenience, fashion trends and technical obsolescence. The majority of material passes through the economy and turns to waste relatively quickly with a low 'residence-time' (Ayres & Warr, 2010), while a portion is embodied in material stocks (e.g., buildings and other structures). The production of this waste has a number of adverse environmental outcomes, for example, plastic waste accumulation in the oceans (Sebille et al., 2015), and the leaching of toxins from landfills (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008). There are also indirect environmental impacts that result from the inefficient use of the resources represented by waste production. Wasted products are replaced with new products that are embodied with environmental impacts (such as energy, water and greenhouse gas emissions) through the extraction and processing of raw materials.

The integration of environmental and economic accounts can greatly assist policy-making and sustainability-related research (Hoekstra & van den Bergh, 2006). In the past, economic data were usually published separately to environmental data (in physical units of MJ, tones or ppm, rather than dollars) and with different classification schemes, this made integration difficult. However, it is increasingly the case that these two accounts are published together. The System of Environmental-Economic Accounting (SEEA), adopted by the United Nations Statistical Commission in 2012 (UN, European Union, Food and Agriculture Organisation, International Monetary Fund, Organisation for Economic Co-operation and Development, and The World Bank, 2014), provides a standardised framework. The Australian Bureau of Statistics (ABS, 2014, 2015, 2016) publishes accounts using this structure, and has so far released water, energy and waste accounts.

Environmental-economic accounts are useful from an analysis and modelling perspective. A useful application is deriving environmentally extended input–output (EEIO) models from the environmental-economic accounts. Input–output analysis (IOA)was first developed by Wasily Leontief in the 1930s (Leontief, 1936) and since then has been applied to a wide range of problems. IOA is a useful tool for conducting supply chain analysis and is capable of enumerating the 'upstream' impacts that occur at each stage in the production of a product or service. IOA has been used to trace environmental impacts through trade networks, for example, calculating territorial greenhouse gas footprints that incorporate global trade flows (Peters, Davis, & Andrew, 2012; Wiebe, Bruckner, Giljum, & Lutz, 2012), and tracing the drivers of biodiversity threats via international trade (Lenzen, Moran, Kanemoto, Foran, Lobefaro, & Geschke, 2012). This approach has also been used to investigate social impacts of trade, for example, global employment outsourcing (Alsamawi, Murray, & Lenzen, 2014) and embodied income inequality (Alsamawi, Murray, Lenzen, Moran, & Kanemoto, 2014).

An important application of IOA is the calculation of consumer environmental 'footprints'. These footprints contain all of the environmental impacts that occur along the supply chains that exist to meet the demand of consumers for goods and services. These environmental footprints are therefore from the *consumption* perspective, as opposed to the *production* perspective whereby environmental impacts are associated with the entity (e.g., industries or households) that directly causes impact, or region in which the impact occurs. Footprints have been calculated for a range of indicators, including ecological (Wackernagel, Lewan, & Hansson, 1999), water (Zhao, Chen, & Yang, 2009) and emissions (Wiedmann, 2009).

In general, waste generation data are published from the production perspective. From this perspective, the environmental impact is attributed to the industry, or region, that directly produces the waste (or some other environmental indicator). This perspective can be contrasted with the consumption perspective, whereby environmental impacts are allocated to the consumers of final products. In Australia, the majority of waste data is published in this manner: waste generation by producing entity. In this chapter, we use a waste input–output (WIO) model to calculate the total waste footprint of consumers by finding the waste produced at each production stage.

WIO Models

WIO models are a class of EEIO model that combine monetary transactions between industries and consumers with physical waste flows. There is a significant history of WIO model construction by a number of different researchers (Ayres & Ayres, 1997; Ayres & Kneese, 1969; Converse, 1971; Nakamura, 1999; Nakamura & Kondo, 2002). There have also been a number of multi-regional waste input–output (MRWIO) models published, including Kagawa, Nakamura, Inamura, and Yamada (2007), Tsukui, Hasegawa, Kagawa, and Kondo (2012) and Tsukui, Hasegawa, Kagawa, and Kondo (2014), all using Japanese data. WIO models have been applied to numerous problems in waste generation and management, including analysing waste metal flows (Nakamura & Nakajima, 2005), demand for landfill (Nakamura, 2000), diversion of food waste away from landfill (Reynolds, Boland, Thompson, & Dawson, 2011), wastewater treatment (Li, Lin, & Huang, 2013) and recycling home electrical appliances (Nakamura & Kondo, 2006).

Recently, a waste supply-use (WSU) format was proposed as an extension to the standard WIO model (Lenzen & Reynolds, 2014; Reynolds, Piantadosi, & Boland, 2014). For monetary input–output tables, the supply-use format can provide more information about an economy than symmetrical industry-by-industry or product-by-product tables. For example, they can show the production of multiple products by an industry (UN, 1999). Similarly, the supply-use format can show more detail in WIO tables. In addition, the WSU formalism allows both waste type and treatment multipliers to be calculated simultaneously.

In this study, we describe the construction and demonstrate the use of a MRWIO model that covers Australian solid waste flows. We extend the WSU format of Lenzen and Reynolds (2014) to include multiple regions. The resulting multi-regional waste supply-use (MRWSU) framework complies with the SEEA (UN et al., 2014) structure for solid waste and extends the detail and scope of the ABS' Waste Account. We combine a number of published waste data sources and align them with the structure of the MRWSU framework. The IELab platform is used to handle data alignment and table reconciliation.

Model Construction Using IE Lab

A number of barriers exist to constructing an Australian multiregional WIO model. Firstly, there is a lack of harmonised waste data. Australian waste data are published by a number of entities including the ABS, federal, state and local governments and industry. These datasets are often not directly comparable because the coverage, classification system and level of aggregation varies between them. In addition, not every reporting entity publishes waste data every year, making it difficult to form a complete time-series of waste data. The human labour required to source and align these data with the input–output structure can make the construction cost prohibitive. In Australia, evaluating waste reduction and material efficiency strategies can be difficult due to the quality of published waste data. First, the data are often highly aggregated in terms of the waste producer (usually it is presented in three categories: commercial and industrial, construction and demolition and households). The data are published by a variety of entities who often use different waste type classifications, hindering comparison between datasets. In addition, some waste data sets are not published every year so a complete time-series cannot be constructed. Significant human labour is required to source and align these disparate data sets.

Producing large-scale multiregional models also presents some challenges. The number of elements contained in a MRIO model grows as the number of included regions, sectors and quantities (e.g., monetary, environmental and social indicators) increases. In turn, the computational requirements of reconciling large-scale models become significant when the number of elements grows very large. For example, the Eora world MRIO database contains approximately 10 elements and required 500 GB of RAM during reconciliation (Lenzen, Moran, Kanemoto, & Geschke, 2013).

The MRWSU framework is constructed using the Industrial Ecology Virtual Laboratory (IELab) a computational platform for constructing Australian MRIO tables. IELab is employed for a number of its useful features: the collaborative nature of the laboratory encourages researchers to pool data and share the work of data alignment, the construction workflow is largely automated, the built-in reconciliation engine produces balanced MRIO tables derived from potentially many data sources, and the regional and sectoral structure of the tables is flexible and therefore adaptable to specific research questions (Lenzen et al., 2014). To date, IELab has been employed to perform a number of studies, including a triple bottom line study of the Australian biofuel industry (Malik, Lenzen, & Geschke, 2016) and hybrid life-cycle assessment (Rodr´ıguez-Alloza, Malik, Lenzen, & Gallego, 2015).

The IELab environment offers a unique approach to data alignment and framework structure. Firstly, all raw data are aligned to a high-detail *root* classification. The framework is then produced at a less-detailed *base* classification by aggregating the root categories. This avoids aggregating the raw data purely to align it with other data. Since all raw data are aligned to the root classification initially, the final framework structure is not 'locked-in' at the data preparation stage. This approach reduces information loss and allows a flexible framework structure that can be tailored to specific research questions. The mapping of the source data to the base classification is achieved in two stages of mapping: first to root and then to the base classification. The basic steps of table compilation are the following:

(i) Define an initial estimate of the table from the source data
(ii) Choose sectoral and regional aggregations (base classification)
(iii) Map the initial estimate to the base classification
(iv) Define constraints on the initial estimate
(v) Reconcile the constraints with the initial estimate

Regional Waste Footprints

The Sankey diagram in Fig. 10.1 depicts waste flows in the Australian economy. From left to right, the diagram shows the waste caused by each subnational

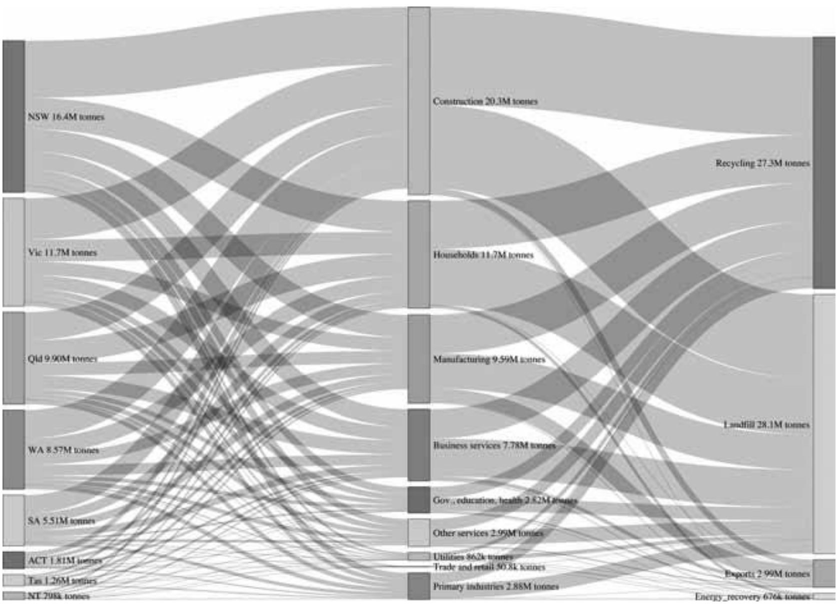


Fig. 10.1: Waste Flows in the Australian Economy; Total Waste Generation, as Measured Using Consumption-Based Accounting, Driven by Consumers in Each of the Australian States and Territories (left), Generating Entity (Industry or Households) (middle), Treatment Type (right). Base Year: 2011–2012.

region (equivalent to the regional waste footprints), the entity directly producing the waste (i.e., industries or households) and finally to the waste treatment sectors. The region nodes on the left-hand side contain the waste footprint for each region. The middle nodes represent the entities (industries and households) directly producing the waste. The industries have been aggregated from 19 to 8 sectors for display purposes. The 'Households' component is all municipal solid waste (MSW). The nodes on the right-hand side are the waste treatment sectors.

Waste generated by households accounts for approximately 25% of total waste produced. Of this, the largest components were food organics (31%), paper and cardboard (20%) and garden organics (17%). The average household recycling rate is 47% while the most-recycled waste type are metals at over 80%.

The average industry recycling rate is 43%, with the highest split achieved by the construction industry (52%). Construction waste is the largest industrial waste flow, accounting for 35% of total waste. The majority of construction waste is rubble (38%), concrete (26%) and bricks (14%). The next largest industrial waste flow is the manufacturing sector (16%) followed by the service industries (23% collectively).

Fig. 10.2 presents a comparison of direct waste production and waste footprints for the Australian states and territories. Fig. 10.2(a) shows direct waste production in kilotonnes (kt) by region and entity. The entity directly produces the waste in the region in which it is located. The direct component of each region's total generation is that waste directly disposed by households and industry in that region. Waste produced overseas (RoW: rest-of-the-world) and then imported to Australia is also shown, the entity is simply 'imports' since typically no information about the RoW entity is given in the data. Fig. 10.2(b) shows direct waste production by region and entity, normalised by population (ABS, 2013a).

Fig. 10.2(c) shows the waste footprints (kt) for each region, broken down by final product. In this plot, the colour indicates which product was purchased by consumers in each region. The indirect component is comprised of waste generated during the production of goods and services purchased by that region. The indirect component includes all waste created by the region's final demand, regardless of the region in which it occurred. RoW refers to waste produced in Australia in order to meet international demand. The 'Households' component is waste produced directly by households and does not change between the direct and footprint results. Fig. 10.2(d) shows the waste footprints (kt) for each region, normalised by population).

The decrease in the total regional footprints compared with the direct waste production case is caused by the reallocation of waste produced in Australia to the waste footprint of international consumers. The waste footprint of international consumers results mainly from purchases of primary industry (mining, agriculture and forestry) and manufacturing products. The footprints also show a reallocation of waste away from the primary sectors and manufacturing, towards the trade (retail and wholesale) and service sectors, such as public administration, education and training and health and social assistance. This demonstrates that even when purchased goods and services do not have an obvious material component, further up the supply chain material-intensive processes exist that produce waste.

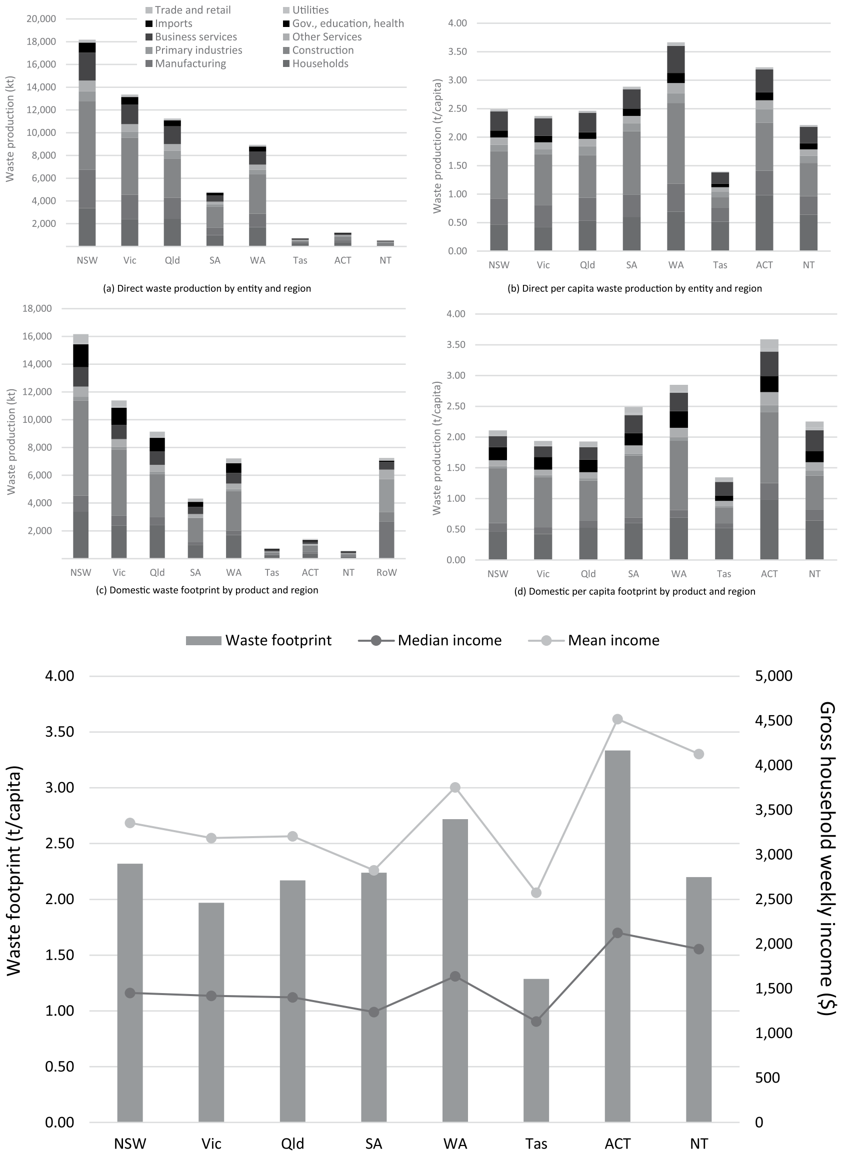
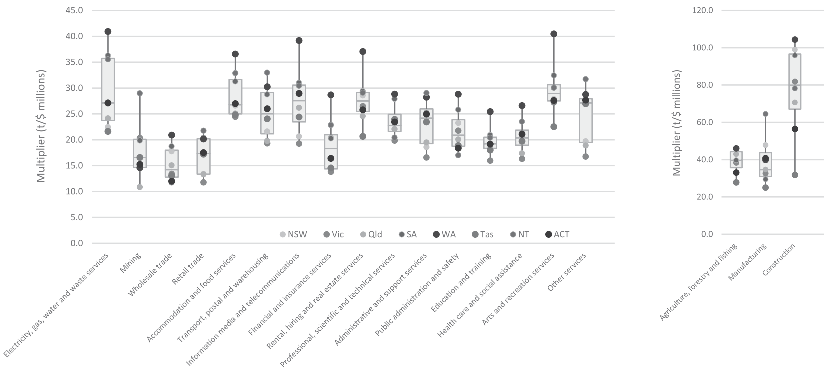


Fig. 10.2: Direct and Full Supply Chain Waste Production in the Australian Economy (2011–2012).

This section compares the industrial waste production multipliers (t/$ millions) between regions. The industry multipliers include the full supply-chain waste production of these industries. The box-plots in Fig. 10.3 depict the waste production multipliers for each of the 19-sectors in the framework as well as the spread in the



(a) Industry waste multipliers

(b) The three top-ranked industry waste multipliers

Fig. 10.3: Industry Waste Generation Intensity (t/$$10^6$ by Region), Including Direct and Supply Chain Waste Production.

calculated value between regions. The industries with the largest multipliers, shown in Fig. 10.3(b) on a separate *y*-axis, are construction, manufacturing and agriculture, forestry and fishing. The Western Australian multipliers are consistently the highest multipliers, while the Tasmanian multipliers are on average the lowest. The largest spread of multipliers occurred between the construction sectors.

Discussion and Uncertainty

While generalised input–output frameworks have been used to address a range of environmental-economic problems, the method contains a number of inherent uncertainties.

The source data contains uncertainty arising from sampling and reporting errors. Not all physical data originates from measurements, some datasets are derived (e.g., tonnages inferred from volumes), while others are estimated (Netbalance, 2009). The data quality also varies with region, reporting entity and waste producer (e.g., household waste data are generally better in quality than industry waste data, see Netbalance (2009) and Hyder Consulting (2012b)). Some errors can also occur when datasets with different classification systems (e.g., published by different reporting agencies) are merged.

The approach used for data alignment and disaggregation also introduces uncertainty. For this study, we have disaggregated the source data somewhat (1 national region to 8 sub-national regions; 8 sectors to 19 sectors), but have also demonstrated a technique for an arbitrary level of disaggregation. This disaggregation partly relies on proxy information, which is imperfect. However, this proxy information is then augmented with other, high-detailed, data that improves this estimate. One of the reasons we disaggregate is to minimise the aggregation bias that occurs when heterogeneous sectors (or regions) with very different environmental impact intensities are grouped together (Bouwmeester & Oosterhaven, 2013; Lenzen, 2011).

The calculation of waste footprints contains uncertainty relating to the proportionality assumption. In standard EEIO models, the trade of physical quantities between industries is inferred from monetary transactions. This results in allocation errors as the price paid for these physical quantities varies between sectors.

A limitation of this work is that the MRWSU framework contains waste production for Australia only, and therefore underestimates waste footprints by not incorporating waste produced overseas. We estimated the magnitude of this effect by calculating the waste produced overseas from Australian imports using the domestic technology assumption. We found that the current method underestimates Australian waste footprints by approximately 1.5 million tonnes. Manufactured products contribute the greatest to the international waste footprint, followed by transportation and warehousing services, and IT and professional services. This method assumes that production processes internationally have similar waste intensities to domestic Australian processes, which is clearly an approximation (Tukker, de Koning, Wood, Moll, & Bouwmeester, 2013). The construction of a global WIO model will allow the international waste footprint of consumers to be more accurately calculated.

Conclusion

In this study, we constructed a MRWIO framework for Australia. The limitations of the published waste data were a significant hurdle for the construction process. As previously discussed, the data are typically highly aggregated, published in a variety of formats and missing time-series entries. In addition, currently no published subnational 'waste account' exists. In the absence of more complete data, the IELab environment provides the necessary tools to construct the table from a mix of data sources. The availability of high quality and detailed waste data is critical to evaluating policies that aim to decrease waste production and promote economy-wide dematerialisation.

As a first application of this framework, we presented waste footprints for Australian consumers that quantify both the direct production of waste by households and full supply- chain waste production. Waste is generated by industry while producing goods and services to satisfy consumer demand. The aim of presenting these footprints is to make visible all waste production that results from consumption and to demonstrate that total waste production is several factors larger than what is typically witnessed by the householder. However, we are not assigning *responsibility* for all waste production to consumers, for a further discussion on responsibility see Lenzen, Murray, Sack, & Wiedmann (2007).

The production of waste is closely linked to the consumption of goods and services. However, a substantial fraction of the total waste production is hidden from the end-user of products and services. Policies aimed at reducing waste production and the associated environmental impacts should therefore target these 'upstream' processes in addition to point-of-disposal approaches. These upstream policy approaches include reuse, remanufacture and design-for-recycle, and can be viewed as part of broader material efficiency initiatives which aim to dematerialise the economy and close material cycles (Allwood, Ashby, Gutowski, & Worrell, 2011; Schandl & Turner, 2009).

Acknowledgements

The work was financially supported by the National eResearch Collaboration Tools and Resources project (NeCTAR) through its Industrial Ecology Virtual Laboratory, and by the Australian Research Council through its Discovery Projects DP0985522 and DP130101293. NeCTAR are Australian Government projects conducted as part of the Super Science initiative and financed by the Education Investment Fund.

We thank the anonymous reviewers for their suggestions which improved an earlier version of this article. Many thanks to Dr Arne Geschke and Dr Chris Dey for their development and operation of the IELab environment, the ABS (Environmental Accounts section) and Dr Anne-Marie Bremner from Encycle Consulting for waste data provision, and Jim West from the CSIRO for the provision of disaggregated physical production data from the CSIRO-UNEP Asia Pacific database. The authors also thank Sebastian Juraszek for expertly managing our advanced computation requirements

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Chapter 11

Renewing Materials: Implementing 3D Printing and Distributed Recycling in Samoa

Lionel Taito-Matamua, Simon Fraser and Jeongbin Ok

Abstract

This research addresses the grave issue of plastic waste in the Pacific. By using Samoa as a case study, it was considered that distributed recycling combined with 3D printing offers an opportunity to (1) repurpose and add new value to this difficult waste stream and (2) engage diverse local communities in Samoa by combining notions of participatory design with traditional Samoan social concepts. Fieldwork in Samoa established the scope of the issue through interviews with stakeholders in government, waste management businesses, the arts and crafts community and education. Based on the information obtained from the fieldwork, potential product areas and designs were explored through material and 3D printing experiments using low-cost, open-source equipment. The experiments informed the design of speculative scenarios for workable, economically viable, socially empowering and sustainable systems for repurposing and upcycling plastic waste, which then enabled production of practically useful and culturally meaningful 3D printed objects, artefacts and products. Building upon the outcome and with a view towards implementation, Creative Pathways, an educational initiative aimed at propagating 3D printing and contextual design, was established and is being delivered in local schools.

Keywords: 3D printing; distributed recycling; participatory design; Fa'a Samoa; plastic waste; upcycling

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 191–212

doi:10.1108/978-1-78714-619-820181016

Introduction

Marine plastic debris has been considered one of the most serious pollution problems since the Great Pacific Garbage Patch was first predicted and corroborated in the 1980s (Dahlberg & Day, 1984). The situation has direct social, cultural and economic implications for pacific nations who rely on healthy marine environments as a source of sustenance and income, as well as reputational capital for tourism (Penaia, 2014).

While there are many ecological initiatives aimed at collecting debris from the marine environment in operation, recent research emphasises that without significant improvements in waste management the amount of plastic waste entering oceans from land will increase significantly by 2025 (Jambeck et al., 2015). Given the scale of the problem, it is unlikely that it will be resolved by any single solution (Eriksen et al., 2014). However, the emerging digital technologies associated with 3D printing have potential to address the aggravating global issue (World Economic Forum, 2017), to disrupt this relentless stream and to raise public awareness (Manyika et al., 2013).

Background

As 3D printing, the technology for the 'next industrial revolution', becomes more affordable and accessible, new scenarios of production are emerging. The advent of a $750 kit printer from Makerbot in 2009 signalled the possibility of a *made@home* revolution. Students at Victoria University of Wellington responded with a *recycled@home* scenario, and the resulting Recyclebot was the first example of a closed material loop in the form of small-scale distributed fabrication and recycling (Fisher et al., 2012). The implications of such scenarios of making and remaking have since been critically discussed in the context of '3D printing a more beautiful landfill' (Lipson & Kurman, 2013) as well as scientific studies into the comparative energy efficiencies of printing with recycled filament (Baechler, DeVuono, & Pearce, 2013; Kreiger, Mulder, Glover, & Pearce, 2014). On the bases of these studies, it was hypothesised that digital technologies and distributed recycling combined with the social and cultural context in Samoa offers a unique opportunity to model a workable, economically viable, socially empowering and sustainable scenario for repurposing and upcycling plastic waste, by reinvigorating it in the form of useful and culturally meaningful 3D printed objects and artefacts. It was also proposed to move beyond the 'prosaic' (Walker, 2014) by revisiting the notion of reduce/recycle/reuse (Alexander & Reno, 2012) with a new and culturally richer strategy of reclaim/remake/reinvigorate, by (1) reclaiming not only materials but also a sense of identity in the onslaught of foreign matter; (2) (re)making as a form of social practice, recapturing in virtual space Samoan practices of sociable creation – transforming production from the anonymous activity it has become, to a more personal, communal activity; and (3) reinvigorating in the sense of giving new life and meaning to matter, rather than attempting to reiterate its previous mass produced purpose.

This represents a design response to much larger issues such as 'social inequalities' and 'environmental destruction' captured by Stuart Walker (2014, p. 86) in his book *Designing Sustainability*:

> The gross social inequalities between and within nations and the vast environmental destruction occurring in the world today have to be tackled in new ways that reach beyond the utilitarian, eco-modernist approaches that still dominate discussions around sustainability. Design can contribute to this debate by challenging industry conventions and contextualizing material culture within a broader and deeper frame of consideration. This involves being far more sensitive to the nature of human work that the making of our material culture represents, as well as to the kinds of materials used, where and how these materials are acquired and the processes used to transform those materials into objects.

It is also a design response that connects to the concept of designing and making as an empowering activity embodied in Klaus Krippendorff's (2008, pp. 14–15) idea of 'cooperative design':

> I am suggesting that designing is fundamental to being human and contemporary society increasingly realizes the fact that making things is fun and the opportunity to play with possibilities, and to invent rules rather than follow those imposed by others, enables people to realize themselves.

Field Research

The first step in exploring the hypothesis involved field research in Samoa. However, prior to travelling to Samoa a range of potential stakeholders and applications for the digital technologies and distributed recycling were collated in a matrix of potential product areas for further development. It included stakeholders such as tourism and government agencies, educational organisations, art and craft communities, the building industry and agriculture and fisheries, with applications ranging from functional implements and spare parts through to souvenirs, craft objects or educational projects. The idea of using these technologies in this way intrigued the participants, who all responded with positive feedback, and notably certain applications such as using 3D printing as an educational aid resonated immediately with them.

Another area of interest was the tourism industry where the notion of gifting recycled craft objects and artefacts to visitors as they leave Samoa serves the dual purpose of raising awareness of the issue as well as relocating a small amount of plastic waste to its probable country of origin.

In undertaking the field research information about plastic waste management was collected from interviews with two main stakeholders, Pacific Recycles, Ltd. (PR) and Secretariat of the Pacific Regional Environment Programme (SPREP). The fieldwork also coincided with the third International Conference on Small Islands Developing States (SIDS Conference) and facilitated meetings with key organisations and businesses attending the conference. An understanding of Samoan traditions and social practices was gained from participating in Teuila (Leo, 2014), Samoa's largest annual festival and celebration of Polynesian culture. This included discourse with experts and professionals in related areas as well as visits to local residents. The following considerations have specific relevance to the project.

Waste Management in Samoa

Samoa has legislation in place with the Waste Management Act 2010 and the National Waste Management Policy 2001. However, the recycling sector consists of only a few independent operators who focus mainly on scrap metal, without an organised recycle collection scheme. In 2010, PR and SPREP exported 7,642 kg of plastic waste to Australia collected between the years of 2007 and 2010 to test the economic viability of plastic recycling as detailed in Table 11.1 (Lee, 2014a).

The financial return did not match investment (Lee, 2014b). Both PR and SPREP subsequently confirmed that plastic is one of their most difficult recycling issues due to its lack of monetary value (Haynes, 2014), and PR concluded that on-island processing is the key to managing this growing waste problem in Samoa (Sio, 2014). This observation provided an economic background for the scenario.

Culture and Tradition in Samoa

A number of seemingly disparate (Dunne & Raby, 2013) traditional social and cultural concepts, practices and sectors were also identified that could provide a valuable starting point for a speculative and integrative design exploration, to enrich the technological context of the hypothesis – to a mutual benefit.

Tree of Life

Fig. 11.1 shows typical applications of various parts of coconut palm as an example of a comprehensive and sustainable use of a local resource; as building materials for the *fale*, or traditional Samoan house, for diverse woven and carved implements and artefacts, as food or fuel, and for a wide range of exportable

Table 11.1: Details of Accumulated Plastic Waste in Samoa (2007–2010).

Description	Quantity (kg)
PET bottles, baled	1,782
PET bottles, ground	155
PVC white, ground	723
PVC tubes yellow, ground	290
Mixed plastic with metal	2,327
Plastic cover black, ground	2,365
Total	7,642

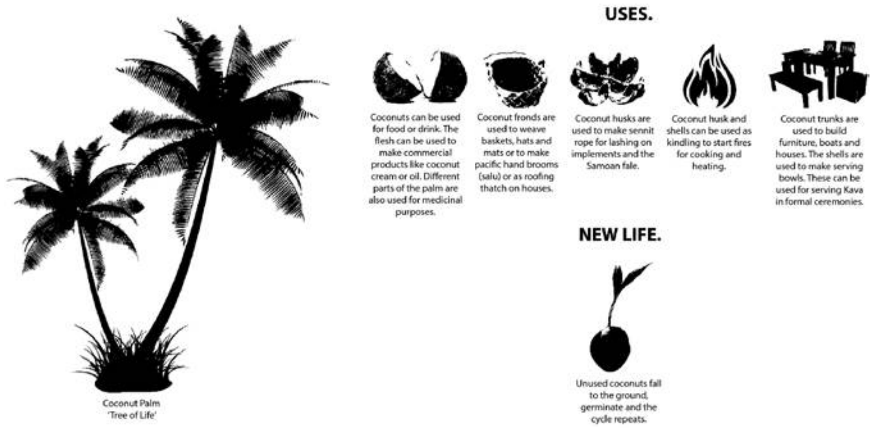

Fig. 11.1: Uses of Various Parts of Coconut Palm.

commercial applications. The tradition of using every part of coconut palm was a key precedent for this study.

Art and Craft

Pacific nations can call on rich and longstanding craft traditions spanning functional structures and implements through to highly decorative and symbolic artefacts. However, the field study revealed that Samoan craft communities are resourceful and not exclusively locked into traditional materials. For example, local artist Naomi Apelu (Fig. 11.2) has moved away from *pandanus*, coconut palms and natural flax, and instead uses recycled plastic bags and palette strapping to create woven place mats, baskets and other traditional Samoan woven ornaments. Her work serves as an important precedent for an adaptable, resilient and innovative culture of craft and making, where new materials and processes are integrated into and enhance traditional practice and vice versa (Taule'alo, V., 2014).

Mea Alofa

Mea alofa is the universal term that Samoans associate with gift-giving. Gifts are presented at any large family occasions such as weddings and funerals, including greeting visitors. Traditionally in Samoa, the customary items which were gifted (*sua*) were fine mats or long lengths of tapa cloth for wearing. However, the old traditions are becoming harder to maintain due to lack of master weavers. The fine mats of today are no longer 'fine' and have no function because most are too bulky to wear (Schoeffel, 1999). This perceived loss of quality represents an opportunity to revisit the link between value and craft – not necessarily in the form of traditional craft, but reinvigorated with digital craft, while at the same time offering an opportunity to revisit the explorations and understanding of digital craft in a new context (Fisher et al., 2012).

Fig. 11.2: Samoan Artist Naomi Apelu. *Source*: Image Courtesy of Tiapapata Art Centre.

Fa'a Samoa

Betham (2008, pp. 2–3) explained the Samoan communal way of life as captured in the term *fa'a Samoa*:

> In Samoan traditional society (…) the matai, village and whole community join in this on-going responsibility of learning and living as the young are instructed, directed and guided in cultural ways and values of respect and good relationships.

Samoa's communal way of life is most evident during times of traditional events and covers various aspects of the Samoan culture including *aiga* (family), *gagana Samoa* (Samoan language), *fa'a matai* (chiefly hierarchy) and *fa'alavelave* (ceremonial and family obligations) (Fana'afi, 1986; Anae, 2014). Extended family, friends and local village neighbours help by sharing their time and expertise with the host family. The idea of coming together as one big family is found throughout Samoa. This concept of community is not dissimilar to online communities where users can share ideas, information and designs, freely available for others to use and modify to suit their purpose – such as thingiverse.com or openstructures.net, which facilitate CAD (computer-aided design) file sharing between users in a participatory design process. Based on the findings, it was hypothesised that these communities – online communities and *fa'a Samoa* – share similar characteristics and therefore could easily coexist, which warranted testing in the field.

Education

Schools in Samoa are a crucial link in developing a viable ecosystem of (re)making. While a digitally capable community is necessary to provide content in the form of 3D digital files for artefacts and products, digital fabrication may in turn offer special opportunities for education in Samoa by supporting a cultural disposition towards kinesthetic and tactile learning (Faleolo, 2013).

This approach to learning has found a new ally in the emergence of the 'Maker Movement' where 'physical "making" is the new frontier' and brings with it a 'making-based model of education' which has far-reaching implications for society. The maker movement is not just about making things, 'it is about developing agency, starting with the physical world, through the use of platforms and technology that make it easier to connect, learn and collaborate' (Deloitte Center for the Edge and Maker Media, 2014). In this respect, the maker movement is not only aligned with modes of learning in Samoa, it also connects to the concept of *fa'a Samoa*.

The Tourism Industry

At 20–25% of GDP, Samoa's economy is largely driven by tourism (New Zealand Ministry of Foreign Affairs and Trade, 2013), and there is a clear awareness of tourism's importance to Samoa, including the need to maintain Samoa's environmental heritage as a 'green, clean, and healthy island' (Leo, 2014) (Fig. 11.3). Typically, tourism and cultural heritage are often closely linked, therefore the tourism industry could be an important conduit for digitally crafted products and artefacts that create compelling narratives and a greater awareness of the marine plastic wastes issue.

The field research provided the social, cultural and economic context for subsequent research activities carried out in New Zealand.

Materials Research and Production Technologies

In order to understand and explore technical issues associated with recycling plastic waste and transforming it into 3D printable filament, a low-cost laboratory was set up (Fig. 11.4). A Filabot Reclaimer from Filabot (Barra, VT, USA), comprising a chainsaw chain linked to a manual crank, was used to grind plastic materials into

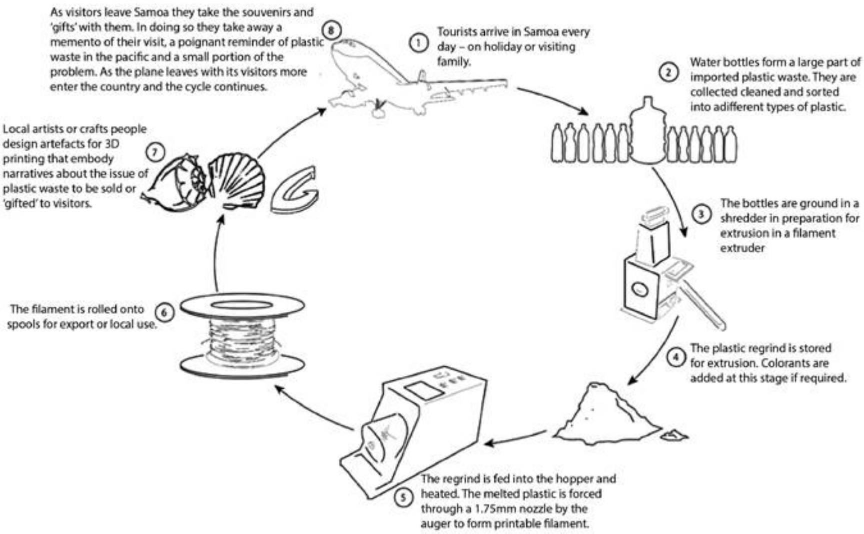

Fig. 11.3: Design Concept for the Tourism Industry.

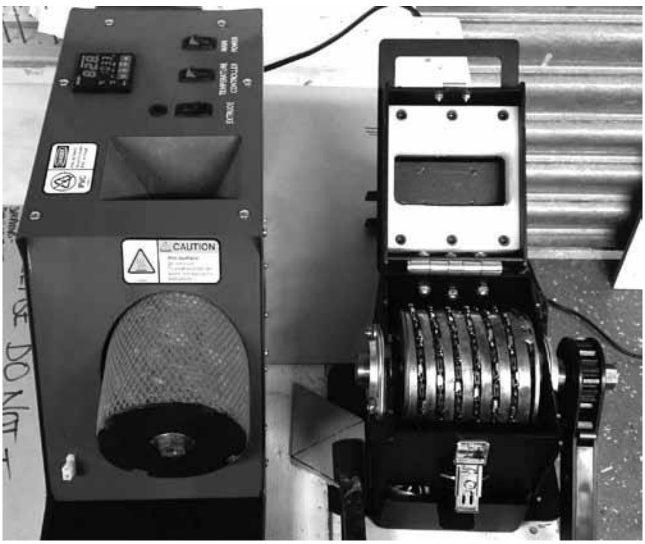

Fig. 11.4: Laboratory Setup – Filabot Original And Filabot Reclaimer.

small particles (about 1 cm × 1 cm), which were then fed into a Filabot Original extruder to produce filament for 3D printing. The laboratory facilitated an iterative and creative process of making, analysing and remaking in response to technical constraints and opportunities, as well as the cultural context.

Materials

High-density polyethylene (HDPE) and polyethylene terephthalate (PET) were selected as main materials for experimentation as they represent the largest constituent in the waste stream globally (Glaser, 2015) as well as in Samoa, based on the statistics gathered from PR. Additionally, acrylonitrile-butadiene-styrene (ABS) and polyvinyl alcohol (PVA; water soluble polymer) were trialled using new resins. Combined, they are the most common plastic materials in terms of both production and disposal in the world (PlasticsEurope, 2015). White milk bottles (HDPE) and clear-to-translucent beverage bottles (PET) were locally collected, washed and dried. An ABS resin and a modified PVA resin from Adept (Auckland, New Zealand) in pellet form were used without further treatment. A blend of HDPE and ABS colour master-batches (CMB from BASF) was also tested as proactive simulation of likely real-world situations such as use of multiple resins in a single instrument without sufficient soring or purging. This also included a wood-filled polymer filament used to simulate a potential filament made with filler from the coconut palm.

Extrusion

Three of the five materials, including HDPE and HDPE + ABS CMB, were extruded successfully (Table 11.2). The ABS portion required extrusion at a higher temperature; however, it improved the average extrusion rate of the blend which measured 340 mm per minute, compared to 290 mpm for HDPE only. On the contrary, PET was difficult to extrude, and the melt formed isolated blobs rather than a uniform strand. It is thought that the PET resins used for bottle production were for injection moulding and did not provide properties needed for extrusion, melt viscosity in particular. PVA was almost impossible to extrude and caused clogging in the extruder because of its excessively low-melt viscosity.

Production

In addition to the materials research conducted, a number of technologies were trialed in order to produce a range of test prints. An Artec 3D scanner from Artec 3D (Luxembourg) was used to scan existing objects and form a 3D digital mesh. Solidworks from Dassult Systèmes (Waltham, MA, USA) and Grasshopper 3D, a

Table 11.2: Extrusion of Various Materials.

Material	Extrusion Temperature (°C)	Overall Quality
HDPE (milk bottles)	135–185	Good
HDPE + ABS CMB	170–192	Good
PET (bottles)	200–260	Poor
PVA (new, pellet)	200	Very poor
ABS (new, pellet)	170–190	Very good

parametric modelling application from McNeel (Seattle, WA, USA) were used to process the mesh and convert it to stereolithography (STL) file format for 3D printing. A UP Mini 3D printer from Tiertime (Beijing, China) with added temperature controls and modified nozzles was used to produce physical models with improved quality. It is expected that the techniques and equipment stated here may be substituted with more user-friendly methods such as smartphone-based scanning apps and open source tools as they become available and accessible in near future.

Postproduction

The resulting prints were treated to postproduction processes such as sanding and colouring using dyes, inks and stains. Traditional crafts such as tapa cloth printing provided inspiration for these postproduction processes, and raised the possibility of combining traditional inks with 3D prints – either as a postproduction surface treatment technique or a colourant during the extrusion of filament.

Design Research

This design research was conducted to address creative responses to the question 'What applications might be suitable for 3D printing and distributed recycling in Samoa?' Using the matrix of potential product areas as a reference, initial design experiments explored what could be made with the recycled plastic material. These ranged from decorative objects to functional implements, and the concepts sought to integrate the technical opportunities offered by 3D printing with indigenous knowledge – by design. The outcome of the design research gave tangible physical form to two speculative case studies; one symbolic and the other more practical.

3D Printed Turtle Skull Gift – Symbolic

An investigation into Samoa's tourism industry revealed that 'Swimming with Turtles' to be a successful tourist attraction. This attraction allows visitors to interact with young or rescued green turtles in an ocean conservation pool at the Satoalepai Turtle Sanctuary on Savai'I. These turtles are rehabilitated in a pool of part fresh and part salt water until they can be released into the ocean.

The turtle occupies a special place in Samoan culture reflected in its name *I'a sa* (sacred fish), but its habitat is severely threatened by ocean-borne plastic waste (Teuten, Rowland, Galloway, & Thomson, 2007). In this case study, a digitally scanned and 3D printed turtle skull (Fig. 11.5) made of locally sourced recycled plastic would be gifted to foreign visitors in the spirit of *mea alofa,* as a reminder of the experience while raising awareness of the plight of these animals.

This gift, a plastic replica of the turtle's skull from the animal interaction experience just enjoyed, embodies the narrative that the material used is exactly the same material that is putting the turtle at risk. The vessel that holds the printed skull references the *fale* (traditional Samoan house) which lends a ceremonial character to the gift and a sacred quality to its contents. The gift serves as a symbolic and tangible reminder of the issue and in accepting it, the visitor becomes

Fig. 11.5: Digitally Scanned Turtle Skull and Shell Presented on a 3D Printed Container.

entwined in *fa'a Samoa,* and comes to play a personal part in disrupting the flow of plastic waste.

Handgrip for a Taro Peeler (asi) – Practical

Field research into the Samoan domestic environment revealed taro as a staple food of the local diet, as well as a range of implements typically used in preparing it for consumption. The *asi* is a household tool used to scrape the outer skin off the taro root. Originally made from locally sourced materials in the form of coconut shells, the traditional version has been discarded in favour of a more convenient alternative – the end of a tin can – most commonly mackerel cans. From the observation, another opportunity 3D printing can offer was identified, which revives the practice of using locally sourced materials, albeit in a new technological context, and delivers customised 'parts on demand' that could endow this, otherwise improvised, implement with more comfort, safety and cultural meaning.

The handgrip for the *asi* (Fig. 11.6) is 3D printed from wood-filled polymer – raising the possibility of combining two materials readily at hand, waste from the coconut palm and recycled plastic – in a 'tree of life' mentality. The small stand (Fig. 11.7) serves as a platform for scraping the taro (Fig. 11.8) or a plinth for storing the handgrip. It references the formal qualities of traditional utensils such as adzes, food pounders and kava bowls and elevates the status of the handgrip beyond disposability to that of an implement that will be kept and valued, and possibly even worthy of *mea alofa*.

Fig. 11.6: Asi Handgrip Design Iterations and form Experiments.
Source: Image by Faitasi Talamaivao.

Fig. 11.7: Asi Handgrip and Stands each with Different Finishes: Sanded and Clear Varnished (Left), Wood Stained (Middle), and Dyed.

Both case studies demonstrate that, far from being a constraint, even the relatively low-resolution settings (about 200 μm of layer thickness) of the UP printer can result in surface qualities not unlike the irregularities found in traditional crafts such as carving. Similarly, the configuration of the support material inherent in the printing process is at times reminiscent of the patterns and structures that are also found in traditional weaving. This suggests the real possibility of maintaining an aesthetic integrity or continuity between traditional craft and digital craft.

Following on from the material research documented in Table 11.2, a third experiment was undertaken using discarded computer keyboards (ABS) to produce recycled filament. Once again, an UP Mini 3D printer was used to print out an iconic Pacific artefact – the fish hook (Fig. 11.9). It is based on existing

Fig. 11.8: CAD Designed Handgrip Which Holds the Asi Used to Peel Taros. *Source*: Image by Ali'inu'u Jansen.

Fig. 11.9: 3D Printed Pacific-Inspired Fish Hooks Made of Recycled Computer Keyboards (ABS).

designs of Pacific fish hooks commonly available around the Pacific, and typically used in traditional ware or as souvenirs at local markets. A leather lashing was added as a visible demonstration of the continuity between traditional craft and digital craft.

These case studies represent only three conceivable scenarios of making in response to the design question. However, in presenting these speculative scenarios (Dunne & Raby, 2013), it can be expected that many more will follow, particularly when the concept is opened to a wider audience. To achieve this, a constellation of localised but interconnected craft communities, school groups and small-scale manufacturers is envisioned where waste plastic is utilised as a newfound resource and value is added in the form of skill, knowledge and cultural content, via online databases and exchange networks that are consistent with *Fa'a Samoa* and open-source sharing. Initial responses to this proposition from stakeholders in Samoa were very encouraging and warrant further research and field-testing, with a view to implementation.

Implementation

The implementation strategy identified two initial key areas that need to be addressed in achieving the aims of the project. The first area of focus is digital literacy. There is little point in imposing a new technology on local communities if they do not know how to use it. The second area of focus is upscaling of the low-cost experimental Filabot laboratory in the form of a Recycling Lab. This is necessary in order to refine both the science and the practical aspects of producing usable quantities of printable filament. For the sake of maintaining momentum, these two areas are being pursued in parallel.

Recycling Lab

The low-cost experimental Filabot laboratory provided a proof-of-concept capability for the initial research project. While the open-source nature of the equipment used was well aligned with the concepts of distributed recycling and maker spaces that underpin the project, it was clear that the science of recycling waste plastic for the production of printable filament and being able to do so in usable quantities, is a challenge that needs to be addressed.

The School of Design at Victoria University of Wellington has responded to the challenge by setting up an experimental preproduction Recycling Lab that will inform both aspects. It includes a twin-screw extruder from Thermo Fisher Scientific (Waltham, MA, USA) for blending and extruding filament, combined with a pelletizer for shredding plastic waste as feedstock for the extruder (Fig. 11.10).

The purpose of the Recycling Lab is twofold: to refine the science of creating filament from recycled plastic while modelling a potential 'micro' production facility in the Pacific.

Fig. 11.10: Lionel with the Twin Screw Extruder and Pelletizer.
Source: Image by Saint Andrew Matautia.

The Recycling Lab also provides a theoretical continuity with the pioneering experiments undertaken by students at the School of Design in 2010 that resulted in the Recyclebot V1.0 (Fig. 11.11).

It provides an in-house facility for recycling the 3D prints and the significant amounts of raft material that are the result of the rapid prototyping process used by many design courses worldwide. Having pioneered the concept of the Recyclebot as an integral component in the 3D printing cycle, the School may consider another global precedent: to close the 3D printing circle by offering students the opportunity to make, print and remake their own filament. It links back to the notion of 'kinesthetic and tactile learning' referred to previously in terms of providing a hands-on experience of sustainable practice in action.

Creative Pathways

Since Computer Aided Design (CAD) plays a significant part in the overall vision and execution of the initiative in Samoa, an outreach programme would be needed to teach local communities how to use the new technology effectively.

In response, a pilot programme Creative Pathways (creative-pathways.com) (Taito-Matamua, Fraser, & Ok, 2016) was established to test the ideas of improving digital literacy in Pacific Island communities, using 3D printing as both a motivator and facilitator. In a systematic strategy, the programme focusses primarily on digital skills with the intention of introducing recycling as a secondary theme later, informed by the research activities in the Recycling Lab.

Using the higher than average Māori and Pacific demographic in the Wellington region (Demographic Resources, 2006, 2013), Creative Pathways was initially designed and planned for local schools with a high percentage of Pacific and Māori students. This offered an opportunity to test projects and student responses under conditions as similar as possible to what might be expected in Samoa. The outreach programme is primarily targeted at years 9 and 10 students (13–15 years old), as it permits greater freedom in configuring courses without

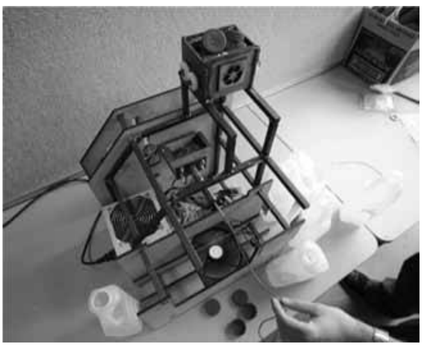

Fig. 11.11: Recyclebot V1.0 Designed and Created by Students from Victoria University of Wellington. *Source*: Image By Paul Hillier.

the curriculum constraints set out by the New Zealand Qualification Authority's (NZQA) National Certificate of Educational Achievement (NCEA) standards and regulations.

Technical Facilities

Creative Pathways calls on existing computer lab facilities in the local schools but provides two Up Mini Desktop 3D Printers to 3D print student work made in class. These 3D printers were selected for their reliability in terms of print quality, functionality, compatibility and the easy-to-use interface. TinkerCAD.com from Autodesk (San Rafael, CA, USA) was also selected as the CAD software as the online tool offers an intuitive interface and device-agnostic access. It also allows students to save and share their work easily.

Project Planning

The initial Creative Pathways project was piloted at Taita College in Lower Hutt, Wellington. Taita was developed in the mid-1940s as a state-housing suburb, supporting the manufacturing industry in Lower Hutt and making it an employment destination for people migrating to New Zealand from the Pacific. (New Zealand History, n.d.). Taita College was selected as the pilot school because of the high percentage of Pacific Island and Māori students (38.9% Māori and 29.9% Pacifika) (Ministry of Education, 2015a).

The project was planned in consultation with Taita College staff willing to introduce new technology into the teaching plan. In order to enhance the learning outcomes and relevance of the 3D printing project, an agreement was made to align the project with teaching material from the mathematics course delivered in parallel. Creative Pathways classes were offered over a period of eight weeks for one hour per week. It was broken up into three separate assignments:

Assignment 1 coincided with the solid geometry section of the students' mathematics course, offering a new perspective on mathematics through a process of 'learning by making'. Students explored basic geometrical principles such as size, shape, form, dimensions and the associated terminology through 2D sketching, followed by 3D CAD modelling and 3D printing. By taking basic forms found on TinkerCad.com and adding specific dimensions, students could print out a variety of forms for comparison with their peers.

Assignment 2 aligned mathematics with design and manufacturing. With an emphasis on the design process, students were taken from concept to final design. Using the theme 'my first favourite toy' for inspiration, students were asked to find images of their toy and reduce it to its most basic form using shapes provided on TinkerCad. Sketches were then transferred back into TinkerCad with specific dimensions for 3D printing.

Assignment 3 was a more design-focussed project, where students combined the skills and processes learned from projects 1 and 2 to create a Christmas-themed design which could be 3D printed for 'gifting'to family and friends in the spirit of *Mea alofa.*

The initial class number of 16 students at Taita College resulted in a 75% engagement rate for a first-time project. In response to further expressions of interest, Creative Pathways was subsequently trialled at Porirua College (21.5% Māori and 71.3% Pasifika) (Ministry of Education, 2015b). The project was coordinated and delivered in collaboration with the science teacher over a 9-week period with two one-hour classes per week. The students were tasked with designing spinning tops (Fig. 11.12), combining geometries and forms with reference to basic design principles such as scale, balance, aesthetics and most importantly function. This gave the students the opportunity to apply the theories of motion that they were studying in their physics course with practical experimentation throughout the creative stage of their 3D printed spinning tops (Fig. 11.13).

Interest from other schools and colleges has grown, and Creative Pathways continues to build bridges between schools and community groups. Collaborations to date include Queen Margaret College (100% female), St Bernard's College (37% Maori and Pasifika students) (Education Review Online, 2016; Viclink, 2016), and community outreach programmes hosted by Te Wananga o Aotearoa in Gisborne in celebration of Matariki (the beginning of the Māori New Year) (Bauld, 2016), and Wellington Basketball Association (2016), upskilling their representative players with tools that can help them grow off the court.

Fig. 11.12: 3D Printed Spinning Tops Designed and Made by Students from Porirua College.

Fig. 11.13: 3D printed objects designed by students from the Creative Pathways Outreach Programme at Porirua College.

Conclusion

The consequences of ocean plastic extend from environmental pollution to deterioration in the quality of life as well as disrupted economic growth. As a response to this serious and worsening issue, a holistic initiative, with a specific focus on Samoa as a model, which embraces design, technology, materials, indigenous culture, tradition, sustainability, education and economic considerations was established through on-site investigation and interviews with potential stakeholders and participants.

The initiative includes a series of experiments to validate the possibility of producing 3D printing filaments using locally sourced plastic materials and low-cost equipment such as an open-source extruder and grinder. A range of artefacts and implements including a sea turtle skull and a handgrip for taro peelers (*asi*) were digitally designed and 3D printed as a way of showcasing the potential for these technologies to support the gift-giving (*Mea Alofa*) and traditional sense of community (*Fa'a Samoa*) in a contemporary context, while increasing global awareness of the issue.

Building upon these efforts, pilot projects aimed at introducing key elements of digital literacy to young students have been launched at several schools and community groups with high Māori/Pacific demographic in New Zealand, in an attempt to capitalise on the typical Samoan students' predisposition to kinesthetic and tactile learning. The outcomes are being used to galvanise and bring together a growing list of diverse partners, including not for profit organisations, business organisations, educational and cultural organisations, funding agencies and government bodies (Table 11.3), as a pathway to further implementation.

Table 11.3: Research Partners in Samoa and New Zealand.

	Type	Location	URL
Partners in Samoa			
Secretariat of the Pacific Regional Environment Programme (SPREP)	Internal organisation	Apia	sprep.org
Ministry of Natural Resources and Environment (MNRE)	Government	Apia	mnre.gov.ws
Ministry of Prime Minister and Cabinet	Government	Apia	samoagovt.ws/tag/ministry-of-the-prime-minister-and-cabinet
Tiapapata Art Centre (Galumalemana Steven Percival)	Arts and crafts	Apia	creativesamoa.com
The Vanya Taule'alo Gallery	Arts and crafts	Apia	vanyataulealo.com
Pacific Recycles	Industry	Apia	mnre.gov.ws
Partners in New Zealand			
The New Zealand Product Accelerator	Research	Auckland	nzproductaccelerator.co.nz
MADE (Multi-property Additive Manufacturing Design Experimentation)	University-Research	Wellington	made.ac.nz
School of Design at Victoria University	University	Wellington	victoria.ac.nz/design
Viclink	University-Industry	Wellington	viclink.co.nz
Te Rōpū Āwhina	University-Mentoring	Wellington	victoria.ac.nz/students/get-involved/lead-mentor/awhina
Taita College	Secondary Education	Wellington	taita.school.nz
Porirua College	Secondary Education	Wellington	poriruacollege.school.nz

(*Continued*)

Table 11.3: (*Continued*)

	Type	Location	URL
St Bernard's College	Secondary Education	Wellington	sbc.school.nz
Queen Margaret College	Secondary Education	Wellington	qmc.school.nz
Te Wānanga o Aotearoa	Vocational Education	Gisborne	twoa.ac.nz
Wellington Basketball Association	Sports	Wellington	wellingtonbasketball.co.nz
Pacific Business Trust	Trust	Auckland	pacificbusiness.co.nz

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Chapter 12

The Current State of Scrap Utilisation by Thai SMEs

Singh Intrachooto

Abstract

The circular economy has become a significant policy in many countries around the world. In order to achieve a circular economy, wasteful use of resources must be reduced and waste products from manufacturing must be reintroduced into production systems. It is, however, impossible to totally avoid scraps from the production of most goods. This chapter describes an investigation of current practices of 108 small-and-medium-sized manufacturers (SMEs) regarding their use of solid wastes or scraps. Of particular interest are the scraps generated by SMEs because they comprise 98.5% of all manufacturers in Thailand. Despite concern regarding the growing volume of scraps from production lines, this study collected data from both factory visits and from manufacturers and found that waste reclamation policies among SMEs are rare. Most factory owners resort to selling off-cuts to formal and informal recyclers as well as dumping scraps in the city's bins. Despite the general recognition of the growing creative industry in Thailand, the use of design has not been considered as a potential solution to this problem by manufacturers. Since failures in scrap reclamation schemes for product designs also hinge on market prospects and opportunities perceived by manufacturers, market strategies in the green economy must be devised. Only then can Thailand achieve circular material flow in its industrial sector.

Keywords: Upcycle; reuse, 3Rs, solid wastes; circular economy; eco-design; waste-to-wealth; SMEs; Thailand; sustainability

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 213–223

doi:10.1108/978-1-78714-619-820181017

Introduction

All manufacturing processes produce leftovers. It is not possible to completely avoid scraps from the production of most goods due to technical, materials and manufacturing constraints (Intrachooto, 2014; Pacelli, Ostuzzi, & Levi, 2015). The goal to achieve a circular economy demands recirculation of materials into production systems to avoid environmental impacts while sustaining the industrial economy (Genovese, Acquaye, Figueroa, & Koh, 2017; Singh & Ordoñez, 2016). The Ellen MacArthur Foundation, established in 2010 to accelerate the transition from an industrial economy to a circular economy, has defined a circular economy as one that is restorative and regenerative by design, whose aim is 'to keep products, components, and materials at their highest utility and value' by returning materials and by-products back into technical and biological cycles (EMF, 2013). The success of a circular system thus hinges on the ability and efficiency in recirculating material discards into production.

Interestingly, there has been limited discussion of the use of design in the context of circular economy, even though design has always been a part of product development and value creation in manufacturing. In recent years, manufacturers as well as individuals have been turning scraps into commercial products of higher quality or value than their comprised elements and have been advocating the effort as a tactic for waste reduction. Freitag (Switzerland), Osisu (Thailand) and Terracycle (USA) have been promoting and practicing waste-to-value management strategies for decades by using scraps as raw materials for product making. Today, such attempts to keep used materials in the material flow remains marginal and face difficulties scaling-up to have any significant contribution towards the circular economy.

Sung, Cooper, and Kettley (2014) studied possible determinants of reusing waste in value creation and found that perceived benefits both economically and emotionally from such an act, combined with tool availability, are vital to reclaiming waste for the production of goods. To support circular economy policies through industrial systems in Thailand, this chapter describes an investigation of the current situation among Thai manufacturers regarding their solid wastes or scraps, and investigates manufacturers perception regarding their off-cuts, remnants, scraps or 'dead' stock. Some manufacturers are unwilling to call underutilised materials 'waste', and try collecting, categorizing and storing them in large warehouses. Some off-cuts have been stored for nearly 30 years, in the hope that one day these remnants could be sent back into production. Rarely does this happen because most scraps get stored floor-to-ceiling, without any designated access. Retrieving these materials for further use becomes tedious and impractical. The research demonstrates that manufacturers recognise that waste should be minimised and that scrap materials are valuable. Yet, off-cuts continue piling up along the production lines. When considering the cradle-to-gate flow of materials used, some materials, such as wood off-cuts from the process of making a dining chair, for example, can be as high as 40% of the total material used, and stone scraps from the production of stone cladding can be as high as 50% (Intrachooto, 2014).

In order to gauge the country's aptitude for developing a circular economy, this investigation aims at identifying the scrap utilisation potential among small-and-medium-size enterprises (SMEs)[1] in Thailand, since 98.5% of all manufacturers in the country are SMEs (OSMEP, 2014).

Methodology

Thailand's National Science and Technology Development Agency (NSTDA), Ministry of Science, has been carrying out a 'Waste to Wealth' project (W2W) since 2009. The project aims at supporting Thai SMEs in achieving closed-loop production – reducing waste that would otherwise go to landfills or incinerators through upcycling processes. Upcycling refers to the reclamation and development of scraps or waste with the intention of creating new products of improved quality, environmental performance and commercial value (Kane, 2010; McDonough & Braungart, 2002; Pauli & Hartkemeyer, 1999). In other words, the W2W project aims to help local manufacturers reclaim their scraps and turn them into high value-added products or new materials, typically through upcycling.[2] Teams of consultants from universities and research institutions were enlisted to diagnose problems, to explore 'value-creation' possibilities from scraps, and to provide technical and design support to participating manufacturers. The 'W2W' project's aims include: (i) to create an awareness of environmental problems from solid wastes; (ii) to exchange design solutions and strategies and (iii) to disseminate knowledge about scraps categorisation, reclamation techniques as well as production processes, among SMEs.

The W2W project managed by NSTDA presented an extraordinary opportunity for data collection on the levels and types of manufacturing waste produced and their differing contexts, because factories are generally unwilling to share such information with outside enquirers. In this case, the assistance they expected from teams of experts to find solutions to their scraps, which might lead to a potential financial return, was an effective incentive to allow the gathering of this primary data. The study described here collected data from two groups of SMEs.

Group 1: during 2009–2014, a total of 65 manufacturers were visited (see Table 12.1). All of the manufacturers were visited at their own request through the NSTDA office. Most of the requests came after the annual W2W exhibitions at the Thailand International Furniture Fairs (hosted by the Ministry of Commerce) that showcased products made from industrial off-cuts (see Fig. 12.1). The inspection process included company presentations, factory walk-throughs, scrap collections along with wrap-up discussions and in-depth interviews. Each factory visit lasted approximately 3–4 hours. To ensure sustainable upcycling, company policy on scrap reclamation is vital. The decision to join the W2W project had to be approved by the top management of the company, thus ensuring participation.

Group 2: in addition to factory visits, a total of 148 surveys were distributed in 2012–2014, of which 43 surveys were completed in full and used for this study (see Table 12.2). The other 105 surveys were incomplete since most manufacturers were unable to provide the specified amount of waste due to their lack of an accounting system or were unwilling to provide necessary information in full

Fig. 12.1: Upcycled Product Exhibition at Thailand International Furniture Fair 2013 and 2014. *Source*: Photo: Author.

detail, such as volumes of wastes from their production line, or details of any waste minimisation methods used, since they did not see sufficient benefits from sharing this information with the research team. These incomplete surveys, however, remained valuable sources of data for rechecking specific aptitudes. A total of nine survey questions, which aimed at understanding the general practices of scrap utilisation among Thai SMEs, covered (i) number of designers and staff, (ii) types of products, (iii) available tools and equipment, (iv) types and volumes of scraps, (v) sizes and shapes of scraps, (vi) disposal methods, (vii) scrap avoidance methods, (viii) barriers to scrap reclamation and (ix) scrap reclamation policies. This combined data-gathering method (factory visits and surveys) was vital in gaining a deeper understanding of the current perceptions and conditions of most Thai manufacturers (Table 13.3).

Table 12.1: Composition of Factory Visits (SMEs Group 1).

Industry	**Number of Manufacturer**	**Percentage (%)**
Wood	27	41.54
Textiles and leather	9	13.84
Construction/Interiors	1	1.50
Metal (steel, zinc and aluminium)	12	18.46
Glass	4	6.15
Plastics	5	7.69
Others (sport, jewellery and food)	7	10.77
Total	65	100

Table 12.2: Composition of Manufacturers Surveyed (SMES Group 2).

Industry	**Number of Manufacturer**	**Percentage (%)**
Wood	7	16.27
Textiles and leather	23	53.49
Construction	4	9.30
Metal (steel and aluminum)	3	6.98
Glass	1	2.33
Plastics/polymer	2	4.65
Others (food and house ware)	3	6.98
Total	43	100

Findings

Our 65 factory visits and surveys of 43 manufacturers showed that most manufacturers were concerned about their growing scrap stockpile but did not really consider this in terms of any related environmental problems. Slightly over half (50.77%) of the factories visited have joined the 'W2W' project to combat their waste problems (see Table 12.4). Nearly half (46.51%) of the manufacturers in the survey have policies or took actions to resolve their waste problems (see Table 12.5). The combined data from both groups showed that approximately half of the manufacturers in Thailand have institutionalised waste management policies (see Table 12.6).

While the data were encouraging, it appeared to go against our five-year observations while conducting upcycling activities through the Scrap Lab at Kasetsart University Architecture (Thailand). Scrap Lab is a design and research centre founded in 2007 and run by academic staff and students from the Faculty of Architecture at Kasetsart University. It aims to develop an innovative ecologically based approach towards reprocessing and recirculating industrial solid wastes, construction debris and community wastes. Since the research team was from Scrap Lab, we are familiar with general upcycling practices, and have consistently observed that few SMEs have given much attention to their waste disposal or reclamation practices. A large fraction of the factories that joined the W2W project only developed waste management policies upon their joining the project. Following a closer examination of all 148 surveys, merely 13.5% (20 out of 148

Table 12.3: Summary of Data Source.

SME Group	**Number of Manufacturer**	**Percentage (%)**
Factory visited (Group 1)	65	60.19
Manufacturer surveyed (Group 2)	43	39.81
Total	108	100

Table 12.4: Factories Joining W2W Project (Group 1).

Factory Visited	Number of Manufacturer	Percentage (%)
Join W2W[a]	33	50.77
Not joining	32	49.23
Total	65	100

[a]Factories that joined W2W projects are those that have waste management policies.

surveyed) developed policies or took any action to mitigate their waste problems. An alarmingly low number of manufacturers actually reclaim and reuse their own scraps. When being viewed internationally, the recycling rate in Thai industry (13.5%) is still among the world's lowest; the overall recycling rates in Saudi Arabia range from 10% to 15% depending on the industries concerned, while that of Japan range from 80% to 90% (Euromonitor, 2013, 2014).

All manufacturers were aware of their growing volume of discards and were eager to minimise waste during production, largely with the intention of lowering their production costs rather than improving their environmental impacts, in this way achieving a higher profit margin. Keys to waste minimisation lie in tailoring tools and equipment, production processes, raw materials management, as well as staff training. This generally requires capital investments such as purchasing new equipment and production control systems, which often is considered a barrier. Despite these manufacturers' best efforts, scraps continue to increase in volume – occupying large warehouse spaces and requiring staffs to constantly sort out and sell off scraps at exceedingly low returns.

Some 'feel-good' scrap reclamation techniques deployed by manufacturers today have included labelling scraps and storing them in a designated area, or developing new items from scraps simply for in-house usage. However, most manufacturers sell off scraps cheaply to recyclers instead of attempting to reclaim them for product development (see Table 12.7). In spite of the growing volume of off-cuts, most manufacturers remain unwilling to risk making an upfront investment in tools, in hiring designers, or in investing the time in prototyping new products from scraps. Designers are mostly perceived as irrelevant, at least in this context. Creating prototypes from waste material is often seen as an ad hoc task,

Table 12.5: Institutionalised Waste Recirculation Policy (Group 2).

Waste Reclamation Policy	Number of Manufacturer	Percentage (%)
Have policy	20	46.51
No policy	23	53.49
Total	43	100

Table 12.6: Waste Management Policy among SMEs (Combined Group 1 and 2).

Waste Management Policy	Number of Manufacturer	Percentage (%)
YES	53	49.07
NO	55	50.93
Total	108	100

a time-intensive one and therefore to be undertaken during 'free-time', rather than during working hours. Currently, popular methods employed by Thai SMEs to manage scraps are as follows:

1. Sell scraps to recyclers cheaply. Informal recyclers pick up scraps at the factory gates. No effort by the manufacturers is required to transport scraps elsewhere. This is a matter of convenience.
2. Incinerate scraps for energy/heat (particularly for wood off-cuts). Most wood furniture factories need to kiln dry their wood supplies. Wood scraps, sometimes of large sizes, become a heat source.
3. Remix with new materials (Recycle) or reuse scraps as fillers. This is most widely practiced among the plastic/polymer manufacturers.
4. Reclaim remnants for production in existing product lines by cutting small components from large-sized scraps to be used for inclusion in existing products.

Despite the availability of scrap materials within their premises, rarely do manufacturers turn scraps into new commercial products. Less than 7% of companies employ formal design as a tool for waste reclamation (Table 12.7). Out of 43 manufacturers surveyed (Group 2), 29 of them utilise in-house designers to work with their own factory wastes. This encouraging data seem to suggest

Table 12.7: Popular Scrap Management Methods (From the 43 Surveys and 65 Visits).

Method	Number of Manufacturer	Percentage (%)
Selling scraps to recyclers	56	51.85
Incinerate for heat	26	24.07
Recycle	8	7.41
Reuse as fillers	6	5.56
Reclaim for new products (design)	7	6.48
Others (donation and city bins)	3	2.78
Total	108	100

some interest in design as a tool for scrap reclamation. However, following a closer re-examination of all 148 surveys, only 20% (29 out of 148 surveyed) sought out ideas from designers to reclaim their wastes for new products. The rest (119 out of 148) did not consider design in terms of a creative waste management tactic. This suggests that design has not been part of a problem-solving tool for wastes mitigation among Thai SMEs, even though there are a number of successful upcycling enterprises, such as Terracycle (USA), Frietag (Switzerland) or Osisu (Thailand).

Even though manufacturers in this study provided lists of barriers to upcycling, the top barrier listed by each of them pinpointed the greatest obstacles to scrap reclamation. By far the biggest barrier to reclaiming scraps for product design listed was the difficulties in dealing with the scraps themselves, since their size and shape vary significantly (see Table 12.8). Factory owners reasoned that such inconsistent scraps would demand great effort both in terms of manpower and time. Factories in this study operate as original equipment manufacturers, who supply products or parts for other brands, both locally and abroad. They are not familiar with designing and developing their own products. This hinders their ability to upcycle, and also their ability to appreciate the value of design. Without a ready market, they hesitate to take risks for fear of poor investment, since all expenses are viewed as direct costs to a product. It must be noted that most Thai SMEs do not allocate a budget for research and development. Storing and taking inventory of their scraps without a committed market seems illogical, and hence is disregarded quickly.

It might be argued that designers are trained with a responsibility to improve people's quality of life and to be committed to sustainable uses of resources through their creative outputs (Bramston & Maycroft, 2014). Most of the scraps generated from manufacturing facilities are the result of design decisions. Integrating design into scrap reclamation like common sense but is rarely practiced among Thai SMEs. Technical hurdles, such as a lack of manpower or storage space, and having inconsistant scraps, could be overcome with proper training and design assistance, while the market prospect could be resolved through appropriate environmental policies and marketing strategies at the state levels,

Table 12.8: Barriers to Scrap Reclamation.

Ranking	Barriers	Number of Manufacturer	Percentage (%)
1	Unwieldy sizes and shapes of scraps	58	53.70
2	Lack of manpower and time	22	20.37
3	Unforeseen market prospect	16	14.81
4	Lack of proper tools and equipment	7	6.48
5	Lack of storage space for scraps	5	4.63
	Total	108	100

because these barriers have prevented the take-up of scrap reclamation among SMEs in Thailand.

Conclusion

This study provides a necessary groundwork to the development of sustainable scrap upcycling strategies in Thailand. Despite the steady growth of upcycled products in the market (Bramston & Maycroft, 2014) and confirmation by marketing experts that upcycled products can enhance the brand image of a company (Munro, 2012), manufacturers, by and large, in Thailand do not reclaim their scraps for new product development and manufacturing. The fear of customers' rejection and lack of market outlets for upcycled products are major obstacles. Scrap management methods, however, varied greatly among product categories: home decoration, fashion, automotive parts, furniture and so forth. Materials such as textile, leather and wood scraps have been upcycled more often than concrete and masonry wastes, for example. This means that there is an opportunity for further studies on product or material upcycling (Burke, Conn, & Lutz,1978; DeBell & Dardis, 1979).

Based on the assessment of the survey and factory visits, the potential for circular production among Thai SMEs is not encouraging, since only a small fraction of manufacturers have institutionalised scrap-reclamation policies or have employed new tactics such as design to recirculate scraps into the production of new products. Sung, Cooper, and Kettley (2015) found that upcycling at the individual level is linked to feelings of personal attachment and satisfaction, but this could be a key hindrance for manufacturers of upcycled products, since decisions on production are by and large now made with minimal customisation for indiviual customers' preferences or emotional inclination.

In response to the growing global eco-market, an environmental labelling system to endorse upcycled products is necessary for widespread commercialisation through green procurement. In this study, we also attempted to find a correlation between the number of designers in a factory and the volume of waste or the reclamation rate. Although we could not identify such a relationship, this study illustrates the state of mind among Thai SMEs, and quantifies how few have considered using design as a tool to manage scraps. Government policies and subsidies on upcycling may need to be instituted, in a similar manner to that instituted in the energy sectors. This should be done in parallel with factory training in scrap categorisation and design collaboration, to ensure sustainable upcycling. This study shows that most factories do not yet have the capacity to upcycle their own scraps and off-cuts.

Acknowledgement

Much appreciation to Jaksin Noiraipoom, doctoral researcher in the Faculty of Architecture, for organizing the data and turn it into a coherent format as well as to Dr Sopapun Sangsupata and Denise Domergue for their assistance in reviewing this chapter.

Notes

1. SMEs in Thailand generally refer to a manufacturer with an annual sale below USD 7 million and number of employees less than 200.
2. Upcycling refers to a reclamation and development of scraps or waste with the intention to create new products of improved quality, environmental performance and commercial values.

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Chapter 13

Unmaking Waste in Construction in the EU and the Asian Circular Economy: A Formal Institutional Approach

Rita Yi Man Li, Li Meng, Tat Ho Leung, Jian Zuo, Beiqi Tang and Yuan Wang

Abstract

The circular economy (CE) proposes that all materials flow in a close-looped system. Waste generated by one production stage may be useful in another. Thus, the idea of a CE is linked to the goal of zero waste (ZW) and promotes a range of sustainable economic, social and environmental benefits in each sector. When we apply this to construction waste management, waste can be managed through reducing, recycling, upcycling and reusing. However, there is an inevitable cost implication associated with this process due to the additional requirement of inventory and waste processing, and this becomes a disincentive to implementing the CE. Formal institutions, referring here to legal rules and regulations, play a critical role in motivating firms and individuals towards a CE. As different countries have different government rules and regulations, and there is limited research on their differences, we review Asia's and Europe's legal rules and regulations relevant to the goal of ZW and CE in the construction sector.

Keywords: Circular economy; construction waste; regulations; zero waste; formal institution; Asia; EU

Introduction

Dijkgraaf and Vollebergh (2004, p. 2) have suggested that solid waste management should regard waste disposal in 'ascending' terms; that is, of waste being

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 225–240

doi:10.1108/978-1-78714-619-820181018

first 'reduced, otherwise recycled, next incinerated and, as last resort, landfilled'. Although today there is more awareness of environmental concerns and of issues relating to waste, the amount of construction waste accounts for around 25–30% of the total waste generated in the European Union (EU) (Wu, Shen, Yu, & Zhang, 2016). In Asia, the latest data published by the Environmental Protection Department in Hong Kong showed that 25% of total municipal solid waste (MSW) generated in 2011 originated from the construction sector (Wu et al., 2016). These wastes not only impose adverse socio-economic impacts but also environmental consequences. Meanwhile, owing to diminishing landfill space available for construction waste disposal, many strategies and techniques for waste management have been proposed (Wu et al., 2016).

As materials production often uses a large amount of energy for extraction, manufacturing and transportation, the optimal solution would be for waste produced in one production stage to be used by another, in the same or other industries, in accordance with the CE (Bonney & Jaber, 2011; Pagotto & Halog, 2016; Yang & Zhang, 2011), so as to achieve the goal of zero waste (ZW). Unlike the traditional linear economy, where there is an endpoint to all 'waste', materials should flow in the form of a circular system, through the lens of a CE. This highlights the importance of a wiser use of construction resources (Su, Heshmati, Geng, & Yu, 2013), where waste from one process can be sent to those who can make use of it, thus moving towards the final destination of ZW. With an increased emphasis on sustainable development, Germany and Japan have acted as pioneers in implementing policies aimed at achieving CE (Geng, Tsuyoshi, & Chen, 2010; Guo et al., 2017).

In the construction industry, waste management is one of the most crucial means through which to facilitate CE (Zaman, 2015; Zaman & Lehmann, 2011a). Ideally, ZW can also lead to a reduction in energy use and greenhouse gas production (Zaman, 2015; Zaman & Lehmann, 2011b). Although the goal seems distant and hard to attain, some pioneer cities have adopted a ZW strategy, and Canberra in Australia was the first city to officially establish a ZW target in 1995 (Connett, 2013; Snow & Dickinson, 2003; Zaman, 2015).

It is imperative to examine a formal institutional approach towards a CE and waste management. Critics may suggest that current production processes are complicated and many hazardous materials are necessarily generated and that landfill is the final destination of waste after considering the economic costs of alternatives. However, the shortage of land has motivated many nations to develop better waste management options (Connett, 2013; Snow & Dickinson, 2003; Zaman, 2015). There are numerous practical hurdles to a CE, such as increasing costs in the production process. Hence, many firms are reluctant in achieving this goal. Consequently, formal institutions, such as governments, through their laws and policies, play an important role in compensating for such market failures. For example, a substantial landfill charge is often considered as one of the major ways to motivate a reduction in waste. In New South Wales, landfill charges motivate contractors to engage in recycling and reuse activities on construction sites so that the goal of ZW can be attained (Li, 2015). Some specific technologies, relevant to the principle of 'Reduce, Reuse and Recycle', widely known as the '3Rs', have been examined, ranging from on-site sorting and prefabrication to selective demolition (Wu et al., 2016). Thus, this chapter attempts to demonstrate how ZW is attainable within the goal of a CE, and the role of formal institutions in moving towards ZW guided by this goal. Furthermore, this chapter highlights how formal institutions in Asia and Europe are advancing waste management in the construction industry, and how ZW is an attainable management goal in practice (Tennant-Wood, 2003).

The CE

While waste increases the cost of production, some products are highly recyclable, such that 95% of this waste can be recycled (Shrivastava, 1995). However, many recyclable materials are scrapped because of their recycling costs. This negates the aims of a CE in practice. Facing resource supply and waste assimilation challenges, along with land degradation, desertification, acid rain, deforestation, water resource depletion, greenhouse gas emissions and loss of biodiversity, CE offers a means to reduce the requirement for virgin materials and resources, thus limiting the production of waste (Geng & Doberstein, 2008).

In traditional linear production processes, resource flows can be categorised into three stages: make, use and dispose (Stahel, 2016). The aim of a CE is to keep the added value of products for as long as possible and to eliminate waste at each stage, thus creating a 'circle' or 'closed loop' in resource and energy use (Smol, Kulczycka, Henclik, Gorazda, & Wzorek, 2015). Through these means, CE aims to create both a healthy economy and an eco-friendly environment (Geng & Doberstein, 2008) by minimizing both pollution and waste from traditional industrialisation (Geng, Zhu, Doberstein, & Fujita, 2009). Successful implementation of CE can be considered in economic, social and environmental terms (Elia, Gnoni, & Tornese, 2017), since it can potentially promote the sustainable development's goal of benefiting these three areas in a 'triple bottom line' (Li & Ah Pak, 2010).

The Role of Formal Institutions in Moving Towards the CE

Financial benefits are often considered as a major motivation in business activities. For example, recycling activities require heavy investments in plants, specialised equipment and labour, beyond the capacity of many businesses (Ordonez & Rahe, 2013). Since a CE is revolutionary, individual companies that adopt it may have to take risks. It is reasonable to expect an increase in costs for new equipment to attain the goal of efficient production (Cui & Jiao, 2014). Nevertheless, some (such as Osterfeld, 1992) have argued that environmental protection impedes economic growth, as evidenced in the past two decades. Therefore, it is valuable to discuss incentives for stakeholders in moving towards a CE. Moreover, it is questionable as to whether it is possible to cover the extra costs likely to arise to achieve the goal of CE development (Cui & Jiao, 2014) and what may be the possible incentive for motivation in this respect. This suggests the importance of the role of formal institutions in motivating the construction industry's participation in the process of moving towards a CE.

Examples of such factors include environmental regulations that promote the competitive behaviour of firms by imposing new costs, generating investment in innovations, improving production and energy efficiency and better observing resource use, energy use, manufacturing efficiency, waste disposal and pollution abatement (Shrivastava, 1995). Environmental regulations and their associated costs eventually affect companies' strategic decisions on sourcing raw materials, locating production facilities and managing energy and wastes (Smart et al., 1992).

Another strand of the literature stresses the possible mutual benefits of cooperation in the industry in the development and implementation of a CE (Cui & Jiao, 2014). For example, in low-carbon supply chain management, cooperation generates a higher degree of mutual trust among industrial partners through sharing information (Yang & Zhang, 2011). The critical challenge is how to construct a reliable platform for companies to interact in this way. Studies suggest that the expected benefits can convince participants to introduce certain management frameworks such as low carbon production, inventory management and so on (Bonney & Jaber, 2011; Bouchery, Ghaffari, Jemai, & Dallery, 2012). Some studies argue that institutional change can act as a booster to cultivate this pro-environmental business environment (Bonney & Jaber, 2011; Cui & Jiao, 2014; Yang & Zhang, 2011), because formal institutions can shift the passive role of businesses to promote a CE more proactively. Since this type of culture shift is never an easy task, the role of institutions is crucial to provide a practical guidance to the industry.

ZW in the CE

ZW is a goal involving process of material transformation resulting in no waste (Li, 2015; Zaman & Lehmann, 2011). ZW is a goal that is ethical, economical, efficient and visionary, whose aim is to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for other use (Zero Waste Europe, 2015). ZW means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources and not burn or bury them. Implementing ZW aims to eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health (Zero Waste International Alliance, 2009).

Similar to the CE, from the vantage of ZW, resources are treated as in a 'closed-loop' system. Some studies suggest that ZW is a more recent form of the CE principle and that these concepts can be brought into beneficial alignment (Ghisellini, Cialani, & Ulgiati, 2016; Veleva, Bodkin, & Todorova, 2017). This chapter agrees that together these concepts can contribute to an ambitious agenda for sustainable development. However, the distinctions between CE and ZW are important to note. Under the notion of ZW, all materials have their own potential use, so that nothing whatsoever needs to be dumped in landfills. Through different types of industrial processes including reuse, recycling and upcycling activities, ZW can be achieved from resource reuse, emission controls, by-product reuse and the eradication of toxins (Curran & Williams, 2012). ZW management is guided by the waste hierarchy generally followed in modern waste management methods (Song, Li, & Zeng, 2015).

Although CE is an ambitious goal, its application has to deal with serious constraints in terms of national and local contexts. While there are effective demonstrations of the CE agenda, actual practices can vary considerably, and introducing a CE can involve trial and error (Su et al., 2013). Beyond its specific ideology, particularly in the construction industry, a CE can be understood most readily as a form of ZW management. The critical point of similarity is the ideal of a closed-loop system of resource use (Tennant-Wood, 2003). Unlike the more comprehensive ideal of a CE, ZW provides a feasible and measurable form of waste management. Cities that have adopted ZW goals can measure their efforts in many dimensions, even in such areas as carbon dioxide emission reduction. However, ZW management still lacks generally accepted indicators (Veleva et al., 2017).

Mathematically speaking, in the field of construction, end of life waste (E_w) is the amount of building elements (in tonnes) which cannot be recovered in the deconstruction process, which is $E_w = B_q - T_r + \varepsilon$, where B_q is the bill of quantity in tonnes, T_r, and is the recoverable items from B_q, and ε is residual. In other words, the amount of building elements that cannot be recovered can be computed as $E_w + \varepsilon = 0$ and $E_E + \varepsilon = 0$, where E_E is the energy lost at the end of life (Smol et al., 2015).

Compared to ZW, the CE concept is more concerned with the whole production process and life cycle, while ZW is focussed on the goal of a more environmentally acceptable endpoint. However, these two ideas share similar goals in environmental improvement, with ZW being concerned with the end of production, while the CE focusses on a closer integration of the life cycle to achieve the same goals (Veleva et al., 2017). Other research suggests that ZW is also holistic and is concerned with the planning and design of products and processes, a necessary precondition to achieve its goals (Pietzsch, Ribeiro, & De Medeiros, 2017).

ZW in China and Europe

In China, 10 years of adopting a CE framework has evolved from waste recycling and efficiency-oriented production towards a more integrated closed-loop system approach to the control of material flows (Guo et al., 2017; Su et al., 2013). In Europe, the idea of ZW has encouraged an approach where disposed materials are treated as assets for others to utilise, resulting in reduction and eventual elimination of toxic materials (Li, Meng, & Kei, 2015).

For example, Denmark's dairy producer Arla Foods has adopted fully recyclable packaging and has reduced half of its production wastes (Veleva et al., 2017). In another case, Unilever North America saved USD $1.9 million after achieving ZW to landfill (Unilever, 2015), which demonstrates how initiatives aiming for ZW can potentially save considerable waste costs. Focussing on recycling and energy generated from waste can also yield cost reductions, but there are more advanced methods to obtain closed-loop material flows that can yield even greater benefits (Zaman, 2015).

ZW management is feasible and, most importantly, evolutionary. However, when we put ZW into the CE agenda, the consequences have a much broader impact. This is mainly because indicators used in ZW management tend to focus on specific areas such as energy consumption, carbon dioxide emission, water pollution and so forth. The next section focusses on the application of ZW in the construction industry.

ZW in the Construction Industry

Arguably attributed to growing public awareness of environmental issues associated with construction activities, particularly the depletion of natural resources and emission of pollutants, the idea of ZW is gaining in importance. Construction and demolition (C&D) wastes are two major by-products in the construction industry that present critical sustainability and CE challenges. This is due to the significant environmental impacts derived from the generation of C&D waste, not to mention that they also result in fast-depleting landfill sites. This is a critical issue especially in those countries/regions with very limited land resources. As a consequence, legislation has been introduced to encourage more pro-environmental behaviour in the construction industry.

Materials and waste management also feature in green building rating tools such as the Leadership in Energy and Environmental Design and Green Building Council of Australia Green Star. Specific credits are given to those design considerations that aim for maximizing the utilisation efficiency of materials as well as reusing or recycling building products. Similarly, it is not unusual that management measures are adopted in various organisations in a bid to minimise the generation of waste during the construction process. These include not only reusing and recycling construction materials but also prevention measures (i.e., 'Reduce'). Indeed, a change of culture and of stakeholders' attitudes towards waste can play a critical role in managing C&D waste (Udawatta, Zuo, Chiveralls, & Zillante, 2015).

The management of C&D waste requires a holistic approach where inputs are needed not only from the traditional project management team but also from other stakeholders affected by waste management practice and performance, such as end users and facility managers. ZW is one of the main characteristics of lean production, since it also aims to eliminate non-value-added activities across the supply chain (Green, 1999), This is closely related to the ecological theory that aiming for a closed-loop system results in resources being used to their maximum extent, with renewable resources especially encouraged (Kibert, Sendzimir, &

Guy, 2000). To achieve the goal of ZW in the construction industry, it is imperative to collect accurate information about material flows over the life cycle of construction projects. This is essential to identify the key areas contributing to the generation of waste, so that interventions can be developed to improve current practices (McGrath, 2001).

There have been debates about whether ZW could be achieved in the construction industry. One of the key arguments is that the generation of waste is avoidable, particularly in small cities (e.g., Kartam, Al-Mutairi, Al-Ghusain, & Al-Humoud, 2004; Yuan & Shen, 2011). Thus, an increasing emphasis has been placed on minimizing waste. It exceeds the scope of this chapter to validate the concepts of ZW or waste minimisation. Rather, it is accepted here that both concepts have their own merits and are worth further investigation. This is reflected in the growing literature on both concepts.

ZW aims at increasing the pace of resource recovery (Zaman & Lehmann, 2011). It encourages resource redesign so that no waste is sent to landfills (Song et al., 2015). The economic value arising from waste processing is also an important factor that motivates companies to engage in ZW activities (Kunz, Ratliff, Blankenbuehler, & Bard, 2014). Besides, ZW does not merely refer to the ideal of sending no C&D waste to landfills, but it implies integrated strategies that treat all materials, energy and waste together to attain its holistic goal (Ball, Evans, Levers, & Ellison, 2009; Pietzsch et al., 2017).

Zero Waste Scotland suggests that there should be no waste and, therefore, no materials will be sent to landfill. Excess construction materials can be exchanged on an online platform; hence, reuse, reduce, recycle and upcycle activities can lead to a reduction in wastes sent to landfill. One such example is Harsco, which recycles 100% of steel slag leading to zero landfill in Saudi Arabia. Subsequently, the company sends these recovered materials for further processing, which can even enhance the value of these 'wastes'. This leads to the steel slag being used as a soil stabiliser (Li et al., 2015).

Content Analysis

According to the latest comparative study by Guo et al. (2017), research that compares CE development across and between regions is quite scarce. Like other comparative studies, this chapter embraced a critical analysis on the implementation of ZW and CE (Elia et al., 2017; Ghisellini et al., 2016; Lieder & Rashid, 2016; Pomponi & Moncaster, 2017) through a content analysis of significant regulations and policies. Although reports on individual countries and cities exist, for example, showing comparisons between cities in China (Geng et al., 2010; Guo et al., 2017; Guo, Geng, Sterr, Dong, & Liu, 2016), there is a lack of a comparative research on ZW policies with a specific focus on the construction industry in and between nations. Much of what has been written to date also fails to assess progress towards CE and ZW at the macrolevel and the role of government within this progress, preferring instead to focus on the corresponding environmental issues, which are typically insufficient to assess progress (Murray, Skene, & Haynes, 2017). The following section suggests a way that this gap in the research might be addressed.

Despite differences in the political economies of diverse nations, business cooperation between construction firms across national borders has become more common. Comparative studies thus have practical implications for those firms that work in a global context. Likewise, government offices can have hands-on information which can be used when they draft any policies for their cities. However, just as industry now needs to share information across borders (Bonney & Jaber, 2011; Song et al., 2015; Veleva et al., 2017) it is equally important for formal institutions in government to share knowledge and policies across borders to achieve the same goal.

The research method used is inspired by a range of qualitative studies on ZW and CE (Bonney & Jaber, 2011; Elia et al., 2017; Guo et al., 2017; Murray et al., 2017; Pietzsch et al., 2017; Pomponi & Moncaster, 2017; Zaman, 2015), using data collected from various leading journals and especially those studies that reflect the influence of formal institutions on the development of CE. This chapter focusses mainly on Asian countries while considering a few cases in western countries, such as those of the EU, for comparison. Attention has been given to waste management and institutional practices since legislation processes and policies do not always mention ZW or CE consciously as their goal. Therefore, this research has focussed on specific policies that advance the implementation of closed-loop material flows in construction materials.

An Overview on the Current Formal Institutions in Asian Countries

Act on Waste Disposal in Japan

Since the 1970s, C&D waste in Japan has been governed by the Act on Waste Disposal and Cleaning. Nevertheless, this has not played an effective role in resolving the country's waste problems. A series of policies have subsequently been adopted or passed to reformulate waste management, which has included C&D waste management since 1991. This reform has proven to be effective in resolving C&D waste problems, with the Environmental Basic Act of 1993 and the Basic Act on Recycle-Based Society of 2000 also making significant steps towards the goal of ZW. These acts embody some important environmental policy principles, and have shifted the paradigm of waste management from disposal to recycling. In addition, other legal tools have been developed, including the Resources Recycle Act of 1991, which provided the legal basis to facilitate recycling (Gao, 2008).

Construction Waste Regulations in the Philippines

The Philippines created a National Solid Waste Management Strategy between 2012 and 2016. This strategy intended to establish sustainable waste management through financing mechanisms that could help create economic opportunities for advancing the reuse of waste. The Philippine government then created the Republic Demonstration 9003, or 'Natural Strong Waste Administration

Demonstration of the Philippines' to decrease the generation of waste at source, encouraging its reclamation. Three years after this demonstration was established, the volume of reuse had expanded by no less than one-quarter (Li et al., 2015).

Construction Waste Charges Ordinance in Thailand

In Thailand, in 2000, it was estimated that between 16% and 34% of MSW sent to landfill in Thailand could be reused; however, only 7% (or 2,360 tonnes/day) was actually reused. In 2004, around 78% of 425 waste storage areas were open dumps with the rest being landfills. Several critical factors contribute to the development of more sustainable waste management systems: financial support, effective administration and clear goals and targets. The government set the charges for the accumulation, transportation and transfer of industrial and C&D waste in order to lessen the incentive to send this material to landfill. Because of these waste dumping charges, close-looped materials usage is now being encouraged.

Extra Funding Incentive in Singapore

Although each Singaporean generated over 1,330 kg of waste every year (ZW Singapore, 2011), a high recycling rate has successfully increased the Semakau Landfill's lifespan to about 35–40 years. Since it is costly to collect and handle waste for recycling, incineration plants have become necessary for the remaining 38% waste (Li, 2015).

The Singapore government charges approximately US$57 per ton of waste from construction sites, a charge that motivates construction firms to reduce wastes sent to landfill. The government has also launched an Innovation for Environmental Sustainability Fund, which is available to construction companies to set up various recycling facilities and plants. The plan is for more than 90% of the waste is to be recycled (Waste Management World, 2015).

Polluter Pay Principle in Hong Kong

In Hong Kong, a charging scheme for construction waste disposal, implemented by the Hong Kong government, has been in effect since 2005 and has been proven to be capable of reducing construction waste (Wu et al., 2016). The government adopted the polluter pay principle to reduce the construction industry's incentives to dump waste to landfill (Government of Hong Kong, 2015; Table 13.1).

Nevertheless, as Hong Kong's land space is very limited, land prices are high and storing waste is only feasible in some construction sites that are very large. The high storage costs deter many contractors from storing waste on site. Under many circumstances, it may be even cheaper to dump waste to landfill than retaining and storing it for future use. This is a different problem to that encountered in Thailand, where waste management practice is more conventional.

Table 13.1: The Landfill Charge Payable in Respect of Each Load of Construction Waste Delivered to a Landfill for Disposal in Hong Kong (Department of Justice, 2016).

Weight of a Load of Waste	Charges
1 ton or less	$125
Exceed 1 ton	$12.5 per 0.1 ton
For a load of waste is impracticable or can cause public health problems	$125

Regulations and Green Building Rating Systems in the EU

In the United Nations sustainable development goals (SDGs), elements of CE appear under the different goals (United Nations, 2015). Although the SDGs are ambitious, to achieve them will require effective formal institutional settings, such as robust policies and laws, to take effect at both national and regional level. Therefore, concrete regulations and policies become more crucial to stakeholders. Construction activity generates many wastes in the EU. C&D waste alone constitutes about one-third of all wastes generated. C&D waste in the 15 core EU states has reached around 180 million tonnes each year, of which only about 28% is reused or recycled. Five Member States, Germany, the UK, France, Italy and Spain, represent about 80% of the total construction market (Brodersen, Juul, & Jacobsen, 2002).

In the EU, Annex III to Directive 2008/98/EC and Commission Decision on the European List of Waste (COM 2000/532/EC) have been established to improve the effectiveness of waste management (EC, 2013b). Apart from these strategies, existing green building rating systems have also considered the performance of construction waste management and have helped improve performance in this area (Wu et al., 2016).

Charges for Waste Dumping in the UK

The construction industry in the UK produces approximately 380 million tons of resources every year and construction waste accounts for more than 40% of the total waste generated in the UK (Gov.uk, 2013b). Construction, demolition and excavation waste in England alone exceeded 91 million ton in 2003 (Osmani, Glass, & Price, 2008). The recovery rate of C&D waste amounted to 93% in 2013, exceeding the 70% requirement promoted by the EU (Gov.uk, 2013a). Even though this progress seems impressive, as construction activities in the UK increase, reducing waste through more effective waste management becomes even more important (Osmani et al., 2008).

Practically all waste is subjected to some controls with regard to logistics management. There are other regulations in this area which are related to construction waste: the Waste and Contaminated Land (NI) Order 1997; the Controlled Waste (Registration of Carriers & Seizure of Vehicles) Regulations (NI) 1999; the Controlled Waste (Duty of Care) Regulations (NI) 2002; Waste Management – The

Duty of Care and a Code of Practice; and the Hazardous Waste Regulations (NI) 2005. In general, construction, excavation and demolition materials that cannot be reused on site become controlled waste, a category that includes household, agricultural, quarry, industrial, commercial and mining waste (Department of Finance and Personnel, 2010). Apart from these mentioned regulations, tax rates are charged at different levels according to the type of materials disposed of in landfill:

- £48 per ton is charged with a lower rate of £2.50 per ton applied to inert waste (Department of Finance and Personnel, 2010).
- £72 per ton is charged for active waste (Her Majesty's Treasury, 2010).

The UK government further tightened controls on C&D waste to meet the requirements of the EU's Waste Framework Directive (2008/98/EC). Although the recycle rate of C&D waste increased from 35% to 61% between 1999 and 2008 after implementing the new legal frameworks, on top of charging all waste generators, about one-fifth of the waste is still sent to landfill. The Site Waste Management Plans Regulations were implemented in 2008 under S.54 of the Clean Neighbourhoods and Environment Act. It requires principal contractors and clients for projects valued at or above £300,000 to prepare and implement a site waste management plan as well as detailed project description, types of waste and estimated quantities to be produced, the actual waste produced and waste management measures on sites. Projects valued at more than £500,000 require even more detailed reports. Failure to submit a sufficient plan can result in penalties of up to £50,000.

As the above suggests, these nations have adopted different approaches towards achieving the goal of waste minimisation and ZW. For example, the UK, Singapore and Japan all now impose financial incentives to move the construction sector towards ZW (Department of Finance and Personnel, 2010). The existing formal institutions that motivate ZW in the construction industry are summarised in Table 13.2. It can be observed that the stick approach is more popular than the carrot approach.

Table 13.2 summarises the existing formal institutions that motivate ZW in the construction industry.

As shown in Table 13.3, recycling has been recognised as the most effective approach in terms of achieving ZW. In contrast, reuse itself has received comparatively less attention.

Conclusions

Generally speaking the construction industry dumps a huge amount of waste to landfills. The idea of the CE, which suggests that this waste can be used by other stakeholders in the economy, implies that ZW can also be attained. The two goals are effectively the same when related to the management of C&D waste. Resources turned into waste in one industry are potentially useful for others (Veleva et al., 2017). With the advent of globalisation, CE does not necessarily have to occur within just one country. This is especially evident in electronic equipment, where waste from top-tier countries can be recycled and resold to developing countries (Hobson, Lynch, Lilley, & Smalley, 2017). Beyond formal forms

Table 13.2: Summary of the Existing Formal Institutions That Motivate ZW in the Construction Industry.

Country	Incentives Given By Various Formal Institutions
Japan	Government *subsidises* a quarter of construction costs
Malaysia	Malaysia government implements regulations to alleviate the environmental burdens: Ministry of Works via the Standard Specifications for Buildings Works (2005), Construction Industry Development Board (CIDB) with its Pembinaan Malaysia Act 1994 (Act 520), the Ministry of Housing and Local Government with its Solid Waste and Public Cleansing Management Act 2007 (Act 672), Ministry of Natural Resources and Environment with its Environmental Quality Act 1974 (Act 127) [65]
Thailand	The BMA Ordinance on Service Charge B.E.2543 sets charges for the collection, transportation and disposal of C&D waste. It aims to reduce the amount of waste sent to landfills [66]
Hong Kong	Polluter pay principles are adopted to charge construction companies that dump waste
Singapore	US $57 per ton are charged for construction waste disposal [53]
The UK	A standard rate of £48 per ton is charged with a lower rate of £2.50 per ton applies to inert waste [61] £72 per ton is charged for active waste [62]

Table 13.3: Effectiveness of Asia Countries and EU in Moving towards ZW.

Country	Effectiveness	Progress of Circular Economy		
		Landfill	Recycling	Reuse[a]
Japan	Achieving effective in dynamic	√	√	
Philippines	Effective motivator		√	¼ to reuse
Thailand	Achieving effective but lack of legal enforcement		√	7%
Singapore	Effective motivator in both penalty and subsidies		√	
Hong Kong	Ineffective	√		
EU	Effective as leading motivator in several aspects		√	√
UK	Effective as leading cooperator with pioneering legal enforcement	√	√	√

[a]Reuse refers as the most preferably ultimate stage of ZW management and CE.

of international cooperation, some cross-industrial cooperation can be found in some of the larger states (Feng & Yan, 2007; Ghisellini et al., 2016). This cooperation needs the support of formal institutions to help coordinate stakeholders and other potential beneficiaries to fully utilise the material loops required by the CE and the goal of ZW.

The CE can link scattered production chains to form closed-loop systems so that ZW can be achieved. This is apparent in the more successful city, or industry, according to the examples noted above. Nevertheless, because waste dumping often takes place on site, in some jurisdictions, such as Hong Kong, the construction industry must also deal with high-storage costs, which can deter practitioners from attaining the goals of ZW.

In overviewing the development of the CE from the perspective of C&D waste, the results of this study illustrate that its implementation can have a significant impact on reducing waste and encouraging recycling. However, in practice most typical responses remain stuck in a conservative middle range of activities dominated by recycling. This rigid condition is a result of a lack of apparent financial and legal motivators to encourage the 'higher order' activities required to implement the CE and attain the goals of ZW.

Acknowledgements

The authors would like to thank Dr Robert Crocker's valuable comments and T. Mak's contribution to this paper.

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Chapter 14

Municipal Solid Waste Properties in China: A Comparative Study between Beijing, Guangzhou and Lhasa

Wenchao Ma, Lina He, Zeng Dan, Guanyi Chen and Xuebin Lu

Abstract

With the rapid development of China's urbanisation and market economy, municipal solid waste (MSW) generation is increasing dramatically. In response to the threat of environmental pollution and the potential value of converting waste into energy, both the government and the public are now paying more attention to MSW treatment and disposal methods. In 2014, 178.6 million tonnes of MSW was collected at a safe treatment rate of 84.8%. However, the treatment methods and the composition of MSW are influenced by the collection area, its gross domestic product, population, rainfall and living conditions. This chapter analysed the MSW composition properties of Lhasa, Tibet, compared with other cities, such as Beijing, Guangzhou and so forth. The research showed that the moisture content of MSW in Lhasa approaches 31%, which is much lower than the other cities mentioned previously. The proportion of paper and plastics (rubbers) collected was 25.67% and 19.1%, respectively. This was 1.00–3.17 times and 0.75–2.44 times more than those found in Beijing and Guangzhou, respectively. Non-combustibles can reach up to 22.5%, which was 4.03–9.11 times that of Beijing and Guangzhou, respectively. The net heating values could reach up to 6,616 kilojoule/kilogram. The food residue was only half the proportion found in other cities. Moreover, the disposal method applied in each city has also been studied and compared.

Keywords: Municipal solid waste; waste properties; disposal methods; physical components; waste treatment

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 241–257

doi:10.1108/978-1-78714-619-820181019

Introduction

Municipal solid waste (MSW) management has been a major issue worldwide, especially in developing countries where the annual generation of MSW has increased dramatically due to rapid industrialisation and urbanisation. MSW management has raised widespread public concern, especially in connection with environmental protection and construction development. However, the technical standards for MSW treatment and disposal are still quite weak in developing countries.

MSW Management in China

With the rapid economic development and urbanisation in China, the generation and collection amount of MSW has been increasing. The collection amount increased from 150 million to 178.6 million tonnes/year from 2004 to 2014, with an annual increase of 1.9% (Fig. 14.1) (NBS, 2004–2014). Moreover, it is estimated that this annual volume will exceed 200 million tonnes/year by 2020 (Zhou, Meng, Long, Li, & Zhang, 2014). Thus, waste management, including safe waste disposal and reuse, has become urgent issues (Chen, Geng, & Fujita, 2010).

The disposal rate of MSW has increased from 52.1% in 2004 to 91.8% in 2014 (Liang & Fan, 2014). In 2014, there were 818 MSW disposal facilities all over the country, including 604 landfill sites with a processing capacity of 335,316 tonnes/day, equal to a total disposal capacity of 107 million tonnes/year, 188 incineration plants with a processing capacity of 185,957 tonnes/day, equal to a total disposal capacity of 53 million tonnes/year, but only a few composting sites.

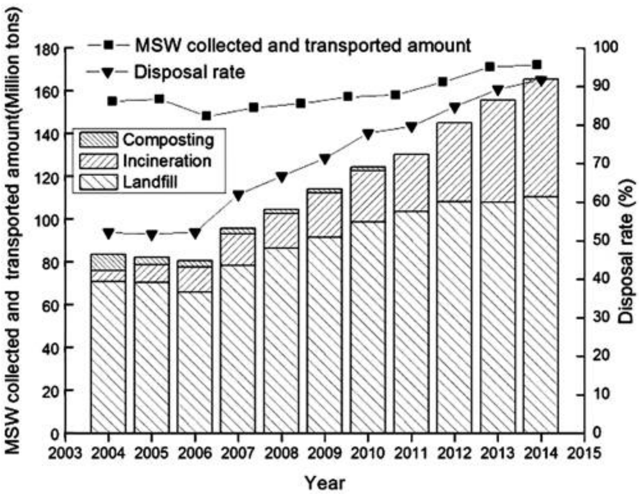

Fig. 14.1: MSW Amount Collected and Safe Disposal Rate from 2004 to 2014. Disposal Rate of Landfill, Incineration and Composting (NBS, 2004–2014).

The proportion of landfill, incineration and other means of disposal was 65.5%, 32.5% and 2%, respectively. While the incineration capacity has increased significantly, and landfill has increased moderately, composting has decreased over the last decade (NBS, 2004–2014). Fig. 14.1 shows the amount of MSW collected and transported and the disposal rate using typical technologies between 2004 and 2014.

The properties of MSW have undergone great changes, with an increase in combustible content (Chen et al., 2010). According to previous research, waste paper, plastics, textiles and wood waste have increased 40% on average in nearly 100 cities in recent years, with plastics increasing most sharply at nearly 50% (Song, Chen, & Zhao, 2014), while wood waste and non-combustibles are decreasing. Figs. 14.2 and 14.3 show the composition of MSW in China in 1996 and 2013, respectively.

The Dominant Disposal Technologies

At present, the dominant MSW disposal technologies in China are landfill and incineration with a very small percentage of compost. The comparison between them is listed in Table 14.1. In addition, MSW pyrolysis is gradually emerging in China at a very small scale.

Sanitary landfill is widely adopted around the world, having the advantage of simple management, low investment and high-processing capacity (Zhang, Tan, & Gersberg, 2010), and this is also now a major waste treatment technology in China (Wang & Liang, 2012). There are some disadvantages, however, for example, low-waste volume reduction, land occupation, site selection restricted by geographical and hydrogeological conditions, difficult-to-treat leachate and landfill gas, which can lead to the contamination of groundwater and soil, and potential explosion. Therefore, landfill is not suitable for densely populated areas with a shortage of land. In 1997, the first MSW sanitary landfill named Xiaoping Solid

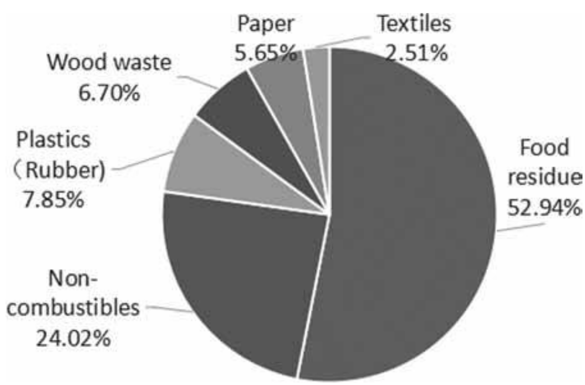

Fig. 14.2: Physical Composition of MSW in China in 1996 (Wang & Nie, 2001).

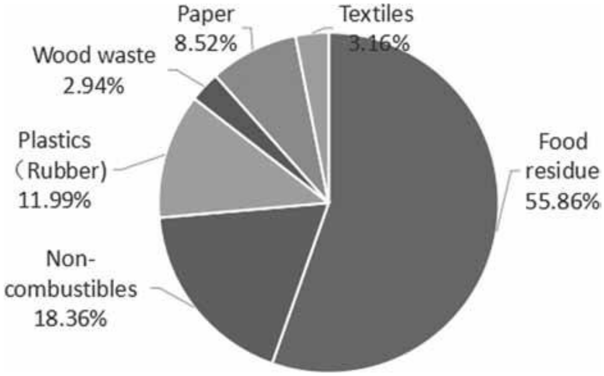

Fig. 14.3: Physical Composition of MSW in China in 2013 (Zhou et al., 2014).

Waste Landfill using a HDPE membrane as liner material was built in Shenzhen (Xu, Li, & Higuchi, 2006). In EU countries, it is not permitted to landfill raw household waste without pre-treatment, emphasizing that landfill is only the final disposal method (Sun, 2013).

MSW incineration technology is spreading fast in China due to its capacity to treat large volumes, hazard reduction capacity and energy recovery. MSW is burned in the first combustion chamber at a temperature of 850—1,000°C, and the gas generated goes through the second combustion chamber at a temperature of 1,200°C in order to completely destroy dioxins, chlorobenzene, chlorophenols and polycyclic aromatic compounds, and finally, using physical and chemical methods, acid gas, dust and so on are removed. The waste heat generated is used directly, as a source of heating, or to generate electricity (Song et al., 2014). The disadvantage of MSW incineration is that it is still easy to release dioxins and other harmful substances. Moreover, a large investment is required to construct, operate and maintain such incineration plants. Thus, large cities in China with strong economies, which are densely populated and have a shortage of land, usually adopt this technology (Wang & Liang, 2012). Thanks to good incineration technology development in addition to an increased capacity to control secondary pollutants, middle or even small-scale cities are considering adopting incineration.

Waste composting is a biochemical process using microorganisms in which the biodegradable organics in MSW can be converted into stable humus (Sun, 2013). In 2010, MSW disposal by composting amounted to only 1.8 million tonnes, around 1.9% of total MSW disposed that year. A declining market demand for composts is one major obstacle. On the one hand, organic waste, such as food waste, suitable for composting, is usually not well separated. Sorting equipment or small-scale manual work requires additional costs and makes composts less competitive in price compared with fertilizers. On the other hand, farmers usually have shown a psychological resistance to using compost made from waste

Table 14.1: MSW Amount Collected and Safe Disposal Rate from 2004 to 2014.

	Landfill	Incineration	Composting
Proportion	Large	Medium	Small
Operation safety	Preferably, pay attention to the fire	Good	Good
Occupation of land	Large	Small	Medium
Site selection	More difficult to consider topographic and geologic conditions, prevention of surface water and groundwater pollution, far away from urban areas, long transport distance	Easy, it can be built neat the urban, short transport distance	Easier, just need to avoid densely populated areas. The odour impact radius is less than 200 m, moderate transport distances
Application condition	Inorganics >60% Moisture content of <30%	MSW low calorific value >3,300 kJ/kg, without adding auxiliary fuel	From the perspective of harmless, biodegradable organics waste ≥10%, From the perspective of the compost should be >40%
Construction investment	Lower	Higher	Moderate
Product market	Recycle biogas for power generation	Generate heat and electric energy	It is difficult to build stable compost market

Source: NBS (2004–2014).
Note: Disposal rate of landfill, incineration and composting.

materials (Chen et al., 2010). At the same time, different sources of compost materials can make the product unstable as some of these contain heavy metals, resulting in a weak demand for composts. The high cost of intermittent dynamic aerobic fermentation, with mechanised processing, and the residue finally released still needing sanitary landfill disposal makes composting technology very ineffective (Wang & Liang, 2012).

Objective of this Research

Previous studies have focussed on MSW management either in China as a whole or in specific target cities. There have been few comparisons made between cities, especially those with different geological locations, climates, living conditions and dietary habits, as well as levels of economic development. This chapter mainly reviews the current composition of MSW and its disposal technology in Beijing, Guangzhou and Lhasa and then makes a comparison between them. The objective of this chapter is to (1) identify MSW composition in these three cities and (2) review the applied technology for MSW disposal.

MSW Management in Beijing, Guangzhou and Lhasa

Cities and Their Policy on Waste Management

Beijing is the capital of China, the centre of Chinese politics, of the economy and science, with an area of 16,411 square kilometres and a population of 12.975 million in 2012 (NBS, 2004–2014). The centre of Beijing is located at a latitude of 39 degrees 54 minutes east, longitude 116 degrees 23 minutes, at the northwest edge of the North China Plain, with an altitude between 20 and 60 metres. It has a typically warm temperate and semi-humid continental monsoon climate, with the average annual temperature between 10 and 12°C. The Beijing municipal government pays close attention to MSW management and has instituted six laws/regulations on MSW from 1993 to 2011. 'Beijing solid waste management regulations' was issued in 2011 (Gao, Dai, & Gao, 2014).

Guangzhou as the capital of Guangdong Province is the third ranking city in comprehensive economic strength in China, with an area of 7,434.4 square kilometres and a population of 8.223 million in 2012 (GSIN). The centre of Guangzhou city is located at a latitude of 23 degrees 6 minutes, east longitude 113 degrees 15 minutes in southern China, with an average altitude of 11 metres. Guangzhou is located in the northern subtropical zone, near the Tropic of Cancer, and its annual average temperature is 22°C with abundant rainfall. Waste classification in Guangzhou started early. 'Municipal Solid Waste Classification and Evaluation Criteria', 'Garbage Classification and Collection Schemes Work' and 'Garbage Classification Marking' were issued in 2004 (Guo, Ruan, & Zhou, 2010). The 'Interim Provisions of Guangzhou Municipal Solid Waste' became a 'rule' in 2013 (Zhang, 2013).

Lhasa is located in the middle of the Tibetan Plateau and is Tibet's transportation hub and political, economic and cultural centre, with an area of 29,518 square kilometres and a population of 500,000 in 2012 (NBS, 2004–2014). The centre of Lhasa is located at a latitude of 29 degrees 39 minutes, east longitude 91 degrees 7 minutes, with an average altitude of 3,658 metres. Over most of the year, Lhasa has sunny weather, less rainfall, with a plateau monsoon semi-arid climate, and an average temperature of 7.4°C. Lhasa deals with MSW in accordance with China's national laws and regulations.

Consequently, Beijing, Guangzhou and Lhasa have significant differences in economic development, climate, location, population, dimensions and living conditions. Fig. 14.4 shows the location of these cities, as well as the MSW generation amounts and altitudes.

Physical Composition Comparison of MSW in the Three Cities

Physical Composition of MSW

Information on MSW components is fundamental to MSW management (Tchobanoglous, Theisen, & Vigil, 1993). In fact, not only MSW generation but also MSW composition is changing. The component of paper and plastics, a sign of rapid urbanisation and economic growth (Zhang et al., 2010), has increased strongly in recent years (Liang & Fan, 2014) and is now similar to Western countries. In addition, it has been shown that residents' income levels are positively related to the daily per capita generation of waste paper and plastics (Qu, Li, Xie, Sui, & Yang, 2009). Table 14.2 shows the physical composition of MSW in recent years in the three cities.

Non-combustibles have decreased from 59.5% to 4.5% over the last two decades in Beijing, resulting from a reduction in wood and coal-fired heating. Contrarily, food waste increased from 24.9% in 1990 to 64.9% in 2010, while recyclables (paper and plastics) increased from 9.5% to 28.0% due to improvement in people's living standards. Textiles and wood wastes did not show much difference. More people going to restaurants with friends and family also increased, resulting in an increase in food waste. However, the proportion of such wastes in Beijing is very similar to that seen in other large Chinese cities, such as the

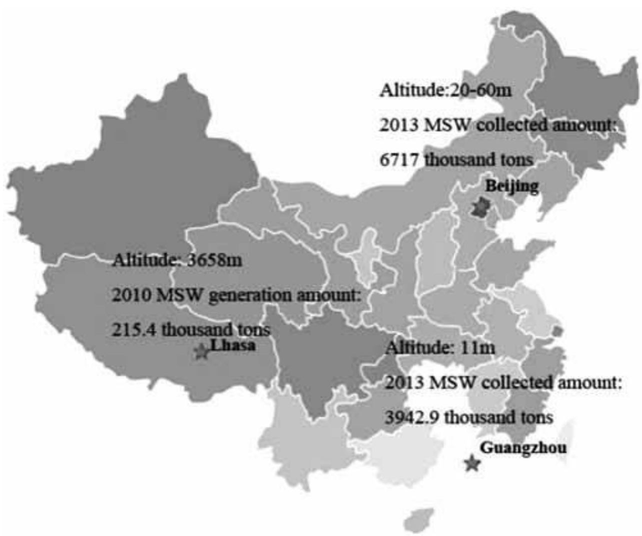

Fig. 14.4: The Location of the Three Study Cities on Chinese Map.
Source: National Bureau of Statistics of People's Republic of China.

Table 14.2: The Composition of MSW in Beijing, Guangzhou and Tibet.

City	Physical composition/%								Reference
	Year	Paper	Plastics (Rubber)	Textiles	Wood Waste	Non-combustibles	Food Residue	Moisture	
Beijing	1990	4.6	5.1	1.8	4.1	59.5	24.9		Wang (2000)
	2000	14.4	13.7	2.0	7.5	18.1	44.4		Xi et al. (2010)
	2005	7.6	11.3	1.8	3.0	21.7	54.6	56.2	Liu (2006)
	2009	12.6	15.3	1.2	3.2	4.5	63.2		Zhou et al. (2014)
	2010	12.9	15.1	3.1	1.5	2.5	64.9		Li (2011)
Guangzhou	1994	2.8	9.6	4.0	–	7.7	76.1		He and Shao (1997)
	2008	9.0	12.6	7.7	7.1	15.2	48.5		Liu et al. (2009)
	2011	8.1	25.6	20.4	2.3	5.9	37.8		Tang et al. (2012)
Lhasa	2006	6.3	11.9	5.3	–	11.7	64.8	46.7	Ciren et al. (2007a)
	2007	6.0	13.0	7.0		1.3	71.0		Ciren et al. (2007b)
	2009	6.0	12.0	7.0	–	1.0	72.0		Jiang et al. (2009)
	2011[a]	23.7	14.8	4.5	2.8	32.7	21.5	24.4	Dan and Bu (2012)

[a]In dry season.

Table 14.3: Comparison of Change in MSW Composition from Different Districts in Lhasa (%).

Zone	**Weight Coef-ficient**	**Paper**	**Plastics (Rubber)**	**Textiles**	**Wood Waste**	**Non-combustibles**	**Food Residue**
Commercial	17.50	27.31	12.85	2.29	9.72	17.91	30.54
Residential	41.25	13.80	15.58	2.83	0.73	45.29	21.78
Business	8.25	61.93	9.62	1.34	4.46	14.51	7.51
Street	28.75	26.93	16.49	2.33	1.33	33.31	19.71
Others[a]	4.25	9.82	15.01	50.77	0.29	2.53	21.44
Average (wt.%)[b]		23.74	14.84	4.5	2.76	32.68	21.48

[a]Hospitals and temples, etc.
[b]The sum of weight coefficient times the percentage of each zone.

Pudong New Area of Shanghai (48%) (Zhu, Fan, Rovetta, & Vicentini, 2009), and Chongqing city (59.2%) (Yuan, Li, Su, & Hu, 2006). This reflects the fact that citizens in large Chinese cities have similar consumption patterns. By contrast, this figure is rather small in small-sized cities and towns, because many citizens there still raise poultry at home and feed them leftovers, while citizens in large cities are not allowed to feed and raise poultry at home. Thus, the proportion of organic waste in small-sized cities is smaller than that in large cities (Xue et al., 2011). Fortunately, the government has realised that too much food was being ordered and wasted in restaurants, especially in north China, and proposed a 'Clean Plate Campaign,' aiming to reduce food waste. This has been in effect since 2014. It can be predicted that this will result in some decline in food waste in Beijing.

In contrast, southern people in China tend to be more frugal and usually do not generate so much food waste from restaurants, so food wastes there have shown a decrease from 76.1% in 1994 to 37.7% in 2011. Due to their lifestyles, southern Chinese people tend to adhere to the rules more consciously and are more aware of the problem of food waste. In recent years, recyclables and textile wastes have increased from 12.4% to 33.6% and from 4.0% to 20.4%, respectively, in Guangzhou. The increases in recyclables and textile wastes are indicators of the growth of the economy in Guangzhou.

The composition of MSW in Lhasa did not change much between 2006 and 2009, except for a decline in non-combustibles from 11.7% to 1.0%. However, one of the coauthors of this paper carried out an investigation of the composition of MSW in the dry season of 2011 (Dan & Bu, 2012), in different functional districts and obtained distinct results, and more details of these are shown in Table 14.3. The big difference in Lhasa may be due to different category definitions and sampling classification.

Comparison of MSW Composition in the Different Cities

The composition of MSW is complex and affected by a wide range of factors, such as geography, population, gross domestic product and living habits. Zhang, Yun, and Hong (2007) indicated that the composition of MSW in China is extremely non-homogenous, and the variation is caused by differences between regions. As can be seen from the Table 14.2, the composition of MSW in the same city changed by year, and the composition of the same year in different cities can also differ.

Food waste prevailed by weight amongst MSW categories. In recent years (Beijng, 2010; Guangzhou, 2011; Lhasa, 2011), the total weight of food residue in Beijing was about 64.9 wt.% (as a proportion of MSW composition) of the overall weight of MSW, which was 1.72 and 3.02 times that of Guangzhou and Lhasa, respectively, due to the high-moisture content of food residue. The moisture content of Chinese MSW is thus usually very high. The proportion of plastics wastes in Guangzhou's MSW was 25.55%, which was 1.70 and 1.72 times that of Beijing and Lhasa, respectively. Paper comprised 23.74% of the overall weight of MSW in Lhasa, which was 1.83 and 2.93 times that of Beijing and Guangzhou, and to some extent, it indicates economic growth in Lhasa. The non-combustible component in MSW in Lhasa was 32.68%, 13.23 and 5.55 times that of Beijing and Guangzhou. The moisture content in Lhasa was 24.39%, much lower than that seen in Beijing. The wood waste fraction was very low, less than 7.5%. Fig. 14.8 shows the fluctuation of physical components of MSW. The amount of non-combustibles and food residue had a wide range of distribution.

The low moisture content and high non-combustible components in MSW in Lhasa are mainly due to the low organic content, large content of dust and the dry weather on the Tibetan Plateau. The moisture content of Beijing was 56.19% in 2005, which was lower than that of Beijing previously, because of an increase in the proportion of food waste. The MSW of Guangzhou has high moisture content and needs to be disposed of quickly due to its easy degradation and generation of leachate (Ding & Mao, 2010).

Paper and plastics, as recyclable waste (Dan & Bu, 2012), occupied a large proportion of 28.01%, 33.6% and 38.58% in Beijing, Guangzhou and Lhasa, respectively (Figs. 14.5, 14.6 and 14.7). According to Dan and Bu (2012), there was 328.57 tonnes of recyclable waste in daily MSW in Lhasa, equal to 120,000 tonnes waste/year. Thus, it is necessary to establish a recycling system for the large number of recyclable components in the MSW not only to save resources but also to reduce the burden of waste disposal (Fig. 14.8).

Progress of MSW Sorting and Recycling

As early as 2000, Beijing and Guangzhou were chosen as demonstration cities to explore MSW source-sorting systems. Beijing classified MSW as food residue, recyclables, hazardous waste and other waste. Guangzhou encouraged the use of a four-category classification: recyclables, hazardous waste, bulky waste and other waste.

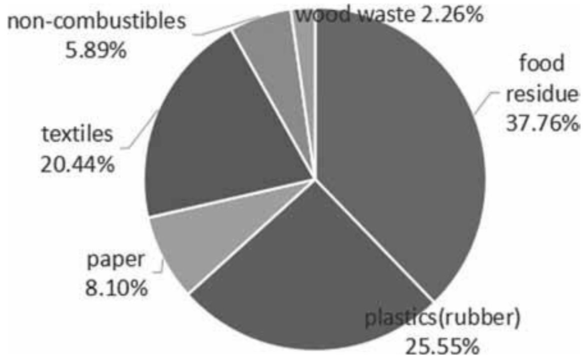

Fig. 14.5: The Composition of MSW in Beijing (2010).

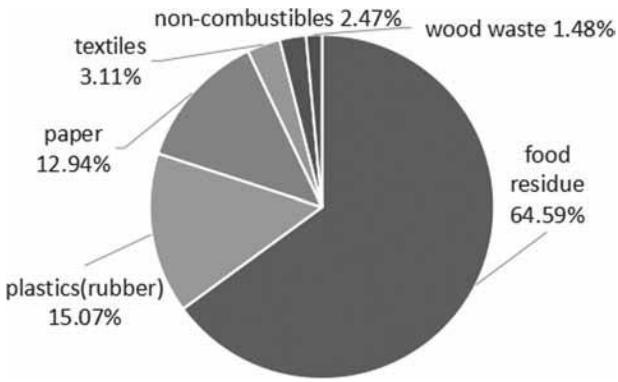

Fig. 14.6: The Composition of MSW in Guangzhou (2011).

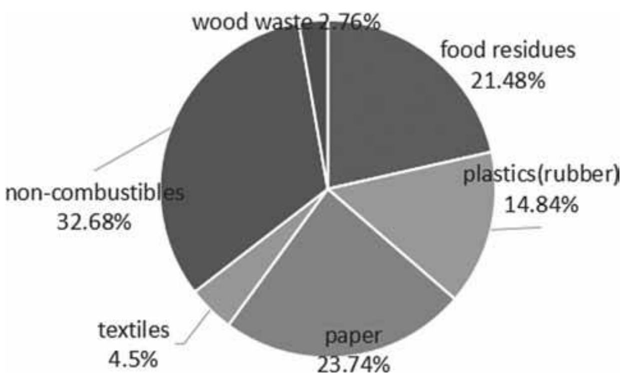

Fig. 14.7: The Composition of MSW in Lhasa (2011).

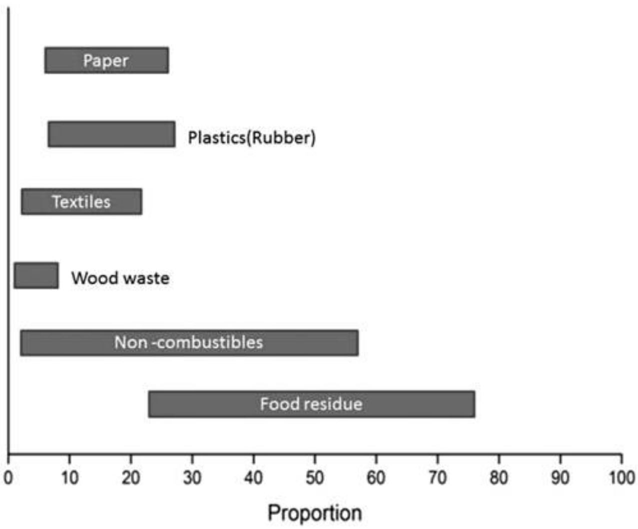

Fig. 14.8: The Fluctuations of Physical Components of MSW.

After years of running these systems, the effectiveness of implementation performance in Beijing has been excellent, with a 54% household sorting rate. In its eight districts, residential communities, offices and public places are equipped with standard classified waste containers. The performance of Guangzhou is at an 'adequate' level. Though the household sorting rate is as low as 10%, the source sorting collection rate reaches 31.9% and depends on the residents' collecting recyclables themselves. In addition, sorting packages and newspaper have contributed to the sorting. A pilot study showed that 326,900 tonnes of renewable resources was recycled, from only 18 streets in Yuexiu District, a testing area for MSW sorting from January to April in 2011 (Tai, Zhang, Che, & Feng, 2011).

In the collection process, recyclables are collected in two ways, either by residents themselves or by scavengers and cleaners who accumulate the recyclables for profit. All these recyclables are sold to recycling companies to be turned into renewable products. The non-recyclables are delivered to collection points and end up in landfills or incineration plants.

MSW Disposal Technology

MSW disposal is a complex and multidisciplinary problem that should be considered in its environmental, social, technical and economic aspects (Mehmet, Kaya, & Kahraman, 2010). Currently, landfill, incineration and composting are the dominant technologies in China. As can be seen from Table 14.4, the proportion of landfill in Beijing decreased from 90.2% in 2005 to 68% in 2012, while the proportion of incineration increased from 2.1% in 2005 to 15% in 2012. Considering social, ecological, economic benefits and other factors, incineration will play a more dominant role in MSW management in the future due to limited land

Table 14.4: Current Status of MSW Disposal in Beijing, Guangzhou and Lhasa.

City	Year	Number of Facility for MSW Treatment/Thousand Tonnes Year			Proportion of MSW Disposal (%)			Yearly Treatment Capacity/ Thousand Tonnes	The Fee of Yearly Disposal/ Thousand RMB
		Landfill	Incineration	Composting	Landfill	Incineration	Composting		
Beijing	2005[a]				90.2	2.1	7.7		
	2007[b]	13	1	3					
	2008[b]	15	1	2					
	2009[a,c]	16	1	2	88.5	3.1	8.4	6,444	
	2012[d,e]	13	3		68.0	15.0		6,372	750,059
	2013[h]	17/4,899	4/978						
Guangzhou	2008[g,f]	/2,444	/355	/0	87.5	12.5	0	2,798.9	
	2009[f]	/2,654	/320	/0	89.2	10.8	0	2,974.1	
	2010[f]	/2,982	/297	/0	90.9	9.1	0	3,279.4	
	2011[f]	/2,843	/365	/6.3	88.5	11.3	0.2	3,213.9	
	2012[e]								120,182
Lhasa	2012[i,e]	1			100			184	1,510

[a]Sun (2013).
[b]Zhao et al. (2013).
[c]Wang (2012).
[d]Liang and Fan (2014).
[e]MEP (2013).
[f]Zhang (2013).
[g]Guo et al. (2010).
[h]NBS (2013).
[i]Ciren et al. (2007a).

for landfill sites in large cities and due to the need for alternative energy supplies (electricity and heat) through waste incineration.

MSW disposal in Guangzhou did not change much over the last decades, with 90% disposed through landfill, supplemented by 10% disposed through incineration. However, the rapid growth of MSW generation will saturate disposal capacity. According to what is known of the current growth of MSW generation and population growth figures, Guangzhou will need 0.067 hectares of land for one day and 24 hectares of land for one year for landfill, which will clearly not be affordable to Guangzhou (Guo et al., 2010). For example, Xingfeng landfill in Guangzhou was expanded in 2012 due to its limited capacity, adding a capacity of 8.4 million tonnes, but finally closed at the end of 2014 (Zhang, 2013). A bottleneck in introducing incineration in Guangzhou is attributed to neighbouring residents worrying about toxic air pollutant emissions, for example, dioxin, and a 'not in my backyard' attitude. In 2009, the government planned to build an incineration plant with a daily disposal capacity of 2,000 tonnes in Panyu District, Guangzhou. However, to this date, the incineration plant has not been built. Moreover, Guangzhou started to use composting techniques in 2011. This added a new possibility to waste diversion and opened up a new path to achieve resource recovery and hazard reduction (especially from food waste) treatment, although the volumes processed are still small (Zhang, 2013).

Currently, landfill is the only MSW treatment method used in Lhasa. The only one landfill is located 35 km southwest of Lhasa. The original design capacity was for 300–400 tonnes/day, to be used for a period of 20 years, and it was commissioned in 2003. With the sharp increase in MSW volumes disposed of in Lhasa, this facility had reached 470 tonnes/day in 2006, and its capacity can no longer meet the future needs of MSW treatment in that city (Ciren, Duo, & Wu, 2007a). Moreover, the design and construction of this landfill facility did not fulfil the necessary environmental criteria and lacks leachate collection and treatment systems, drainage facilities and gas collection or discharge systems, and so might lead to secondary pollution problems (Dan & Bu, 2012). Therefore, new MSW treatment methods are being proposed now, such as waste recycling, waste incineration power generation, composting, and so on. A waste-to-energy plant in Lhasa was planned and started in April 2014, with a first stage capacity of 700 tonnes/day, and a second stage capacity of an additional 350 tonnes/day, namely 1,050 tonnes/day in total with a generation capacity of 200 million kilowatt hour/year (GC). This will greatly ease the burden on waste disposal in Lhasa and extend the life of its landfill facility. Unfortunately, the incineration plant is still being developed, with the project hampered by the city government's lack of experience in this technology.

Conclusion

Rapid economic development, urbanisation and improving living standards in China are creating the demand for more effective and efficient MSW management. This chapter reviewed the current status of waste management, including waste generation, waste composition, sorting and recycling and disposal methods in the cities of Beijing, Guangzhou and Lhasa, with a comparison made between these cities. The chapter's main findings and recommendations are outlined below.

Non-combustibles have decreased from 59.5% to 4.5% over the last two decades in Beijing, resulting from a reduction in the use of wood/coal-fired heating. Contrarily, the proportion of food waste has increased in this city from 24.9% in 1990 to 64.9% in 2010, while paper and plastics wastes have increased from 9.5% to 28.0%, due to an overall improvement in people's living standards. Textiles and wood waste production did not show much difference over the same period. The proportion of food waste in Guangzhou's MSW decreased from 76.1% in 1994 to 37.7% in 2011, while that of recyclables and textiles increased from 12.4% to 33.6% and from 4.0% to 20.4%, respectively. The composition of MSW in Lhasa did not change too much between 2006 and 2009, except for a decline in the proportion of non-combustibles from 11.7% to 1.0%.

Disposal technology in Beijing is 68% through landfill, and 15% through incineration in 2012. MSW disposal in Guangzhou has not changed much over the last decades, with 90% disposed of through landfill, supplemented by 10% through incineration, while landfill is currently the only MSW treatment method in Lhasa, although incineration is being developed there.

Food waste occupies the largest proportion in waste streams, containing high moisture content, and so it is strongly recommended that it should be separated for collection and recycling. Source sorting and recycling as a significant process in MSW management should be strengthened. It is also suggested that MSW should be classified into recyclables, kitchen waste, hazardous material, and other wastes.

Acknowledgements

The authors are thankful to NSFC (51776139), National High Technology Support Project of China (2017YFC0703101 and 2014BAC02B03) and High Technology Support Project of Tianjin (16PTGCCX00170, 16YFXTSF00540 and 16YFXTS F00500).

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Part IV

Technology and Systems Innovation

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Chapter 15

Green Manufacturing: From Waste to Value Added Materials

Samane Maroufi, Claudia A. Echeverria, Farshid Pahlevani and Veena Sahajwalla

Abstract

Every year, tens of millions of the 1.4 billion cars on the world's roads are decommissioned. While the ferrous and other metals that constitute about 75% of a vehicle by weight can be readily and profitably recycled, the remaining mix of plastics, glass, composites, complex materials, fragments and contaminants are mainly destined for landfill as automotive shredder residue (ASR). For every car, approximately 100–200 kg of ASR is disposed of in landfill, posing a growing technical and environmental challenge worldwide. The recovery of the ASR for high-end application is the focus of this study, aiming to optimise the use of these valuable resources and minimise the extractive pressure for raw materials, a future green manufacturing, contributing towards a zero waste circular economy. As the dissolution of carbon into iron is a key step in the manufacture of iron-carbon alloys, the feasibility of utilizing the waste polymers within ASR as sources of carbon in different areas of pyrometallurgical processing was investigated. Polypropylene and rubber, in a blend with metallurgical coke, were used as carbonaceous substrates and the slag-foaming phenomenon was investigated via the sessile drop technique in an argon environment at 1,550°C. The results indicated the rubber/coke blend achieved significantly better foaming behaviour, and the PP/coke blend exhibited a moderate improvement in slag foaming, in comparison to 100% metallurgical coke. The overall results indicated the incorporation of ASR had significant improvement in foaminess behaviour, increasing furnace efficiency.

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 261–279

doi:10.1108/978-1-78714-619-820181021

Keywords: Recycling; Waste plastic; Iron and steelmaking; slag foaming; carburization; high temperature

Introduction

End-of-life vehicles (ELVs) have long been recognised as both a valuable source of readily recovered ferrous and other metals and as a serious and growing environmental threat. Vehicles are approximately 75 wt% metallic (Chemistry Australia, 2000), but constant pressures to reduce production costs and to improve performance and fuel efficiency are driving the integration of ever more polymers, composite materials and embedded electronics into new vehicles. This fast changing, heterogeneous and potentially toxic non-metallic fraction of ELVs, known as automotive shredder residue (ASR), is discarded after metals recovery. In contrast to well-established metal recycling processes, the technical barriers to the economically viable recycling of ASR are significant. New options are critically needed worldwide, to optimise the management of ASRs. Ideally, these would be processes that can facilitate the recovery of the many potentially useful secondary resources within the mixture, and so both drive a market for these resources, while simultaneously neutralizing the environmental impact of this problematic waste stream.

The millions of tonnes of ASR generated worldwide every year are currently mostly destined for disposal in landfill, where this carbon- and hydrogen-bearing waste stream generates greenhouse gases, including large amounts of CO_2 and (up to 50%) methane, as well as posing a real risk of contamination, given the presence of various toxic elements within the shredder residue. Alternatively, in Japan, for example, where land is too scarce for landfilling, ASR is directed into energy recovery. However, this is not a profitable option (Despeisse, Kishita, Nakano, & Barwood, 2015). As vehicle numbers continue to grow, the technical and environmental challenges ASR presents will only intensify.

The total number of passenger cars worldwide passed the one billion mark for the first time in 2010 (Automotive Recyclers Association, 2012) and 1.2 billion in 2014 (Li, Bai, Yin, & Xu, 2016). In 2015, steadily rising global production rates put some 68.56 million new cars and 22.12 million new commercial vehicles onto the world's roads (Statista, 2000). The number of ELVs decommissioned in any one time period, and their fate, is more difficult to accurately determine, given the great variation in reporting requirements and waste management processes and regulations within different regions and jurisdictions. However, based on an assumed annual average scrapping rate of 7%, approximately (Auto QQ, 2012) 84 million vehicles were decommissioned globally in 2014. In the United States, some 11.3 million vehicles were reported scrapped in 2013 (Statista, 2015), in the European Union the total number of ELVs rose from 6.3 million to 9.0 million between 2008 and 2009, and in China, now the world's biggest and fastest growing vehicle market, rapid increases in vehicle ownership pushed similar increases in the numbers of ELVs. Few detailed statistics are available for China, but one recent paper estimated the number of ELVs in China for 2015 at 8.31 million and, with car ownership rates doubling every four years, some 14 million ELVs are projected to be decommissioned in 2020 (Li et al., 2016). Every single decommissioned car currently leaves behind some 100–200 kg of ASR waste (based on a typical car of ~1 tonne).

Conventional ferrous materials such as steel, iron and high strength steel make up some 68 wt% of an ELV. Non-ferrous materials including aluminium, copper and magnesium account for 9 wt%. These metallic fractions of ELVs can be easily recycled and reused and processes are well established. The non-metallic fraction, the ASR, includes plastics, foamed plastics, rubber, fluids, glass, paper, textiles, wires, wood and residual metals (Gent, Menendez, Muniz, & Torno, 2015) and makes up approximately 23% of an ELV (Chemistry Australia, 2000).

The types of plastics within ASR are themselves highly variable and may also contain a range of additives and colorants (Gent et al., 2015). According to the US EPA, about 80% of an ELV vehicle by weight can currently be recycled and major markets have policies in place to drive recycling; the European Union and China, for example, are targeting high recycling rates of 85–95% of all ELVs. From 2015, EU legislation mandated a 95% minimum rate of reuse and recovery for ELVs. Given that ASR makes up some 23 wt%, these gains must be achieved through advances in the reuse and recycling of ASR.

One potential approach that is attracting increasing interest is the potential use of ASR, or its components, as industrial feedstocks that would help meet recycling targets while at the same time reducing demand for raw materials for production and, therefore, cutting costs for industries that can integrate ASR into their processes (Buttker, Giering, Schlotter, Himmelreich, & Wittstock, 2005). Therefore, defining suitable industrial applications for the end-of-life polymeric materials within ASR is crucial not only for the successful cascading use of materials and the implementation of a local cradle-to-cradle circular economy but also for advancing science and technological innovation to meet that goal. The relevance of this approach is not only at the economic level. Avoiding the environmental degradation of increasing landfill volume with its leakage of hazardous elements to natural systems, minimizing the extractive pressure for virgin plastics from fossil feedstocks and reducing the impact on climate change through gas emissions are worldwide issues of major concern.

Different components of the polymers typically detected in ASR sample mixtures are shown in Fig. 15.1. It can be seen clearly from the plastic blend; polypropylene (PP) and rubber have high proportions of 27.14 wt% and 15.7 wt%, respectively, altogether representing 42.8 wt% within the ASR.

In recent years the utilisation of waste polymers in different areas of pyrometallurgical processing such as waste rubber in electric arc furnace (EAF) steelmaking has been widely investigated (Gupta, Sahajwalla, & Wood, 2006; Hilding et al., 2005; Sahajwalla, Hong, & Saha-Chaudhury, 2005; Sahajwalla, Rahman, Hong, & Saha-Chaudhury, 2005; Sahajwalla et al., 2011; Zaharia, Sahajwalla, Khanna, & Koshy, 2009). The use of waste polymeric materials as rich sources of carbon and hydrogen was found to be beneficial in a variety of pyrometallurgical processes. When polymers are utilised as input in pyrometallugical processes, they are transformed into gases and residual carbon products are formed. Depending on chemical composition, molecular structures and bond types, the performance

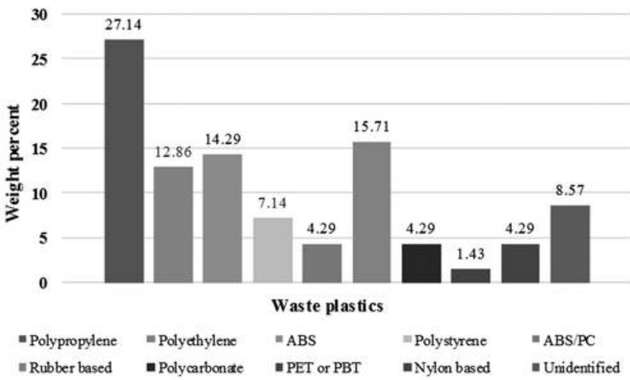

Fig. 15.1: Weight Percent of Waste Plastics Detected in Automotive Shredder Residue (ASR).

of different polymers will vary in terms of their potential to generate beneficial gases and residual carbon. This thorough investigation resulted in our commercialised *Polymer Injection Technology (PIT)*. PIT allows steelmakers to substitute a meaningful proportion of metallurgical coke in its EAFs with a precisely calibrated blend with end-of-life polymers, as a carbon injectant. The result is a novel recycling solution, which transforms problematic waste into a resource for steelmaking. The new polymer-coke blend also improves the foaminess of the slag, and therefore, furnace efficiency. The incorporation of *PIT* into commercial furnaces in Australia (Sahajwalla et al., 2013), for example, has achieved a 12–16% reduction in coke consumption, generated significant power savings and has diverted over two million waste tyres from landfill to date, transforming them into value-added steel products. Given, the demonstrated commercial and operationally benefits of *PIT*, the same, or a similar approach, for waste auto plastics demanded investigation.

This chapter reports on the results of our research defining the feasibility of using ASR waste polymers as sources of carbon in reaction with slag and metallic iron in different pyrometallurgical processes. As rubber, PP and polycarbonate (PC) are components of ASR, this work investigated the application of these polymers in blends of PP/coke and rubber/coke, in interaction with slag and their effect on the slag foaming phenomenon. In the second part of this work, waste PC was used as the carburizing material in reaction with metallic iron and carbon dissolution into molten iron was determined. The results of our studies to date in the high temperature transformations of various wastes, as well as the advantages of blending various mixes of polymers, compared to utilising them separately, suggest that opportunities for utilizing automotive waste as a resource for future green manufacturing are broad. Furthermore, by determining the optimum proportions of different polymers in the mix, the rate of gas generation or the amount of residue of solid carbon can be largely controlled, and each polymer blend can be fine-tuned to meet the requirements of the manufacturing process in which the mixture will be applied to achieve optimised outcomes.

Materials and Methods

Materials Characteristics

A thorough characterisation of the ASR samples was carried out. Automotive waste polymers are heterogeneous in nature and were segregated manually based on visual inspection (colour and physical shape). Segregated samples within the range of 5–10 cm were selected and examined for their polymer contents. Fourier-transform infrared spectroscopy (FTIR) measurements were carried out to identify the functional groups and the composition of each sample. The waste samples were scanned using Spectrum 100, PerkinElmer FTIR. The FTIR spectra clearly confirmed the presence of different polymers such as PP, PC and rubber (Fig. 15.2).

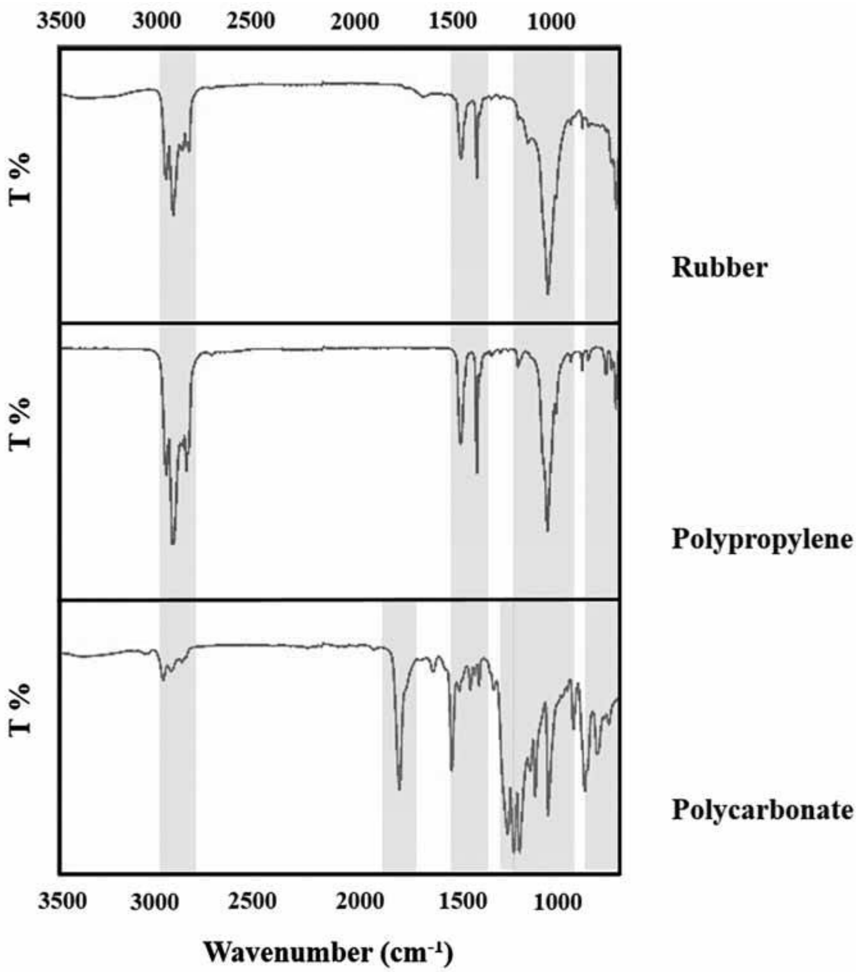

Fig. 15.2: FTIR Spectra Recorded for Rubber, Polypropylene and Polycarbonate Present in Automotive Shredder Residue (ASR).

These polymeric materials vary in chemical structure and composition and are made up of simple carbon, hydrogen backbones or more complex structures incorporating oxygen and/or nitrogen. The molecular structures of polyurethane (PU), PP, PC and rubber are illustrated in Fig. 15.3.

PP is linear in structure and composed of the monomer C_nH_{2n} (Sahajwalla, Rahman, et al., 2005). PP contains ~86% carbon and ~14% hydrogen. It is classified as a thermoplastic polymer, with low density between 0.89 and 0.92 g/cm^3. Hence, it is widely used for low-density applications in packaging, labelling, textiles and stationary areas.

PU is made up of a combination of carbon, hydrogen, oxygen and nitrogen in a range of proportions, for example, $C_{25}H_{35}NO_3$. $C_{15}H_{21}NO_5$ is the composition of most thermosetting polymers. PU polymers are composed of urethane linkages. PU has extraordinary properties such as low density, flexibility, resistance to abrasion, thermal insulation, electrical insulation, toughness, resistance to fatigue, and hence is widely used in cushioning, shoes, building panels and in electrical equipment (Gordon & Wilkie, 1990).

The term 'PC' describes a polymer which is composed of identical units of Bisphenol A connected by carbonate-linkages in its backbone chain. The molecular formula of the PC repeat unit is $C_{16}H_{14}O_3$. PCs are strong, stiff, hard, tough, transparent engineering thermoplastics that can maintain rigidity up to 140°C and do not begin to decompose until about 380°C (Sahajwalla, Rahman et al., 2005).

The structural characterisation of these materials was studied using X-ray diffraction (XRD) technique. Fig. 15.4 illustrates the XRD spectra for coke, rubber and PP. Coke has an intermediate structure between graphitic and amorphous, a so-called turbostatic structure or random layer lattice structure. A high silica peak is seen as suggesting the presence of high ash content. The PP sample exhibited well-defined crystallinity as sharp peaks are predominant in the diffraction spectra, whereas rubber revealed a highly amorphous structure.

Experimental

Pyrometallurgical processes were carried out over a wide range of temperatures. Depending on the target temperature, polymeric materials can exhibit different behaviours. Waste PC was selected to examine this polymer's behaviour during

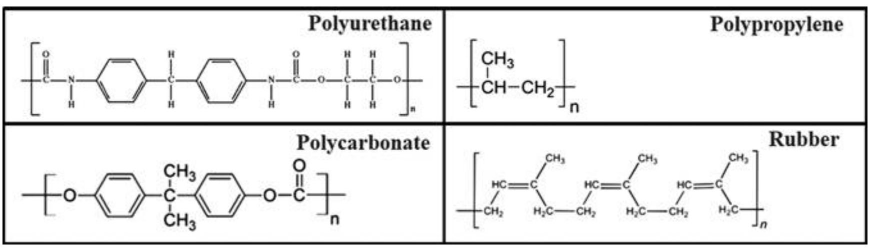

Fig. 15.3: Molecular Structures of Polymeric Materials.

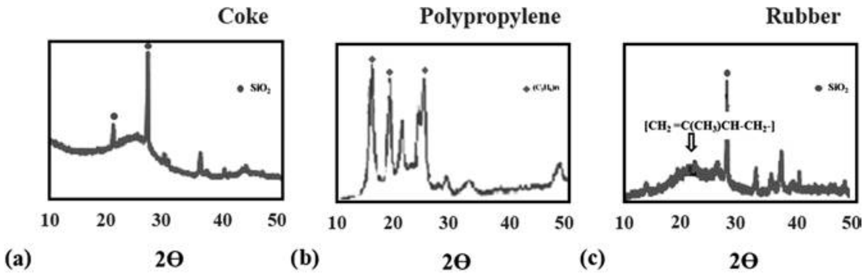

Fig. 15.4: XRD Patterns of (a) 100% Coke, (b) PP and (c) Rubber. *Source*: Sahajwalla et al. (2013).

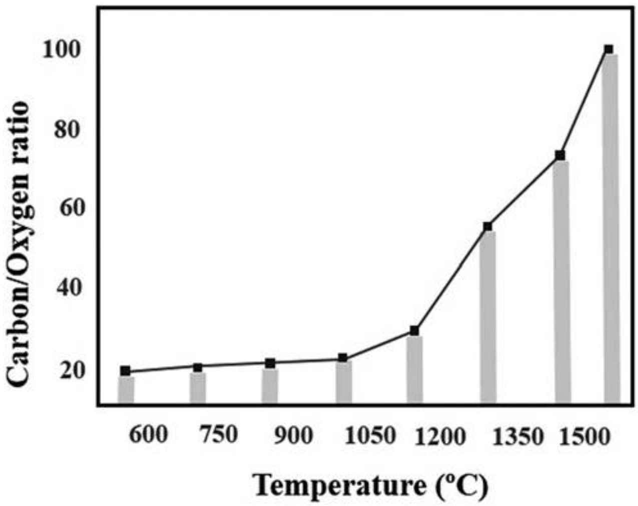

Fig. 15.5: Change of Carbon/Oxygen Ratio during Rapid Heat Treatment of Waste PC at Different. *Source*: With permission Rajarao et al. (2014).

heat treatment. Thermogravimetric analysis was performed to gain knowledge of the thermal transformation of waste PC at a heating rate of 10°C/min in a nitrogen atmosphere from room temperature to 1,550°C (Rajarao, Mansuri, Dhunna, Khanna, & Sahajwalla, 2014). It was found that the carbon yield decreased from 23% to 19% when the temperature increased from 550°C to 1,550°C. The decrease in the yield was due to an increase in primary or secondary decomposition in char residue at higher temperatures. The increase in carbon/oxygen ratio clearly indicated the increase of the aromatic and carbonaceous nature of chars (Fig. 15.5).

Metallurgical coke/PP (or rubber) in powder form was blended in a particular proportion and processed in a rolling mill for four hours to achieve homogeneity. The prepared blends were pressed into cylindrical discs of 20 mm diametre. For investigations of slag-foaming phenomena using PP/coke and rubber/coke blends, industrial slag was used.

The carbonaceous material/slag interaction and experiments were conducted in a horizontal tube furnace (with inside diametre of 50 mm) under argon inert atmosphere at 1,550°C. The schematic of the experimental set-up is shown in a previous study (Kongkarat, Koshy, O'Kane, & Sahajwalla, 2011). The experimental procedure for waste polymer and slag reactions involved monitoring live-in situ phenomena and observing the changes in the volume of slag droplets using a high-resolution camera sitting outside the furnace. The sessile drop technique was used for this purpose.

In the second part of this work, waste PC was used as a carburizing material in reaction with iron. The same horizontal tube furnace was used, and the heat treatment of waste PP was carried out under isothermal condition at 1,550°C. Approximately 1 g of PC carbon residue was used and, as per the procedure described above, a compacted char substrate was made. The compacted carbon substrate was placed on a graphite sample holder and then 0.5 g of 99.98% pure electrolytic iron was placed on top of the substrate. The structural ordering of char structure as the function of thermal transformation temperature was investigated by the XRD technique.

Results and Discussion

Metallurgical coke and its blends with PP and rubber were used as the carbonaceous sources in reaction with slag. The proximate analyses of coke, PP and rubber are presented in Table 15.1. As can be seen, metallurgical coke and PC are at extreme opposites as PP contained the highest amount of volatile matter while fixed carbon is high in metallurgical coke. Rubber is situated somewhere in between in terms of its content of fixed carbon and volatile matter. The chemical compositions of industrial slag measured by X-ray fluorescence are shown in Table 15.2.

Table 15.1: Proximate Analysis for All Samples.

Material	Fixed Carbon	Volatile Matter	Ash	Sulphur	Moisture	Hydrogen
Metallurgical coke	71.5	3.0	15.3	0.32	4.6	1.11
PP	0.74	98.80	0.45	0.092	0.01	13.9
Rubber	30.2	63.2	5.7	2.0	0.9	7.6

Table 15.2: Chemical Analysis of Industrial and Synthesised Slags.

	CaO	Fe_2O_3	Al_2O_3	MgO	SiO_2	MnO
Slag #1 (Industrial slag)	31.1	33.9	6.1	10.7	13.0	6.2

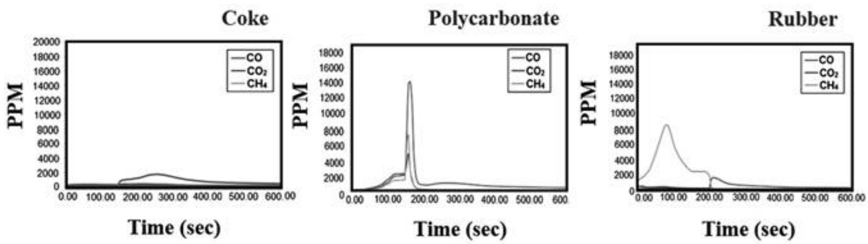

Fig. 15.6: Gas Generation from Blank Coke, PC and Rubber in Argon at 1,550°C as a Function of Time.

The slag volume changes were attributed to the formation. An infrared gas analyser (IR) was also used to measure off gases released from the system during the process of reduction. The moment the slag started melting was marked as the beginning of the contact time.

Fundamentals of Material Structures and Associated Characteristics

An IR off-gas analyser was used to analyse gases generated from the substrate of three samples, for each 100% coke, PC and rubber. Fig. 15.6 shows the various concentrations of CO, CO_2 and CH_4 released during the heating of coke, PC and rubber in argon at 1,550°C. In the case of PC, a significant amount of CO was generated, while the concentration of CH_4 released from rubber was the highest among the materials studied. Compared to polymeric materials, coke generated much less CO and CH_4 gases. Given that hydrogen, methane and CO can play a significant role in reducing metal oxides in pyrometallurgical processes, waste polymers can be considered as a valuable source of reducing gases (Fig. 15.6).

Fig. 15.7 presents the XRD profiles of waste PC chars produced at different thermal transformation temperatures. In all spectra, two peaks were observed clearly over the examined range 10–80º, corresponding to the diffuse graphite (002) and (100) peaks in low and high 2θ regions, respectively (Lu, Kong, Sahajwalla, & Harris, 2002). The shift of 2θ angle, as a function of temperature, towards a higher angle shows the decrease in the contents of amorphous carbon and the aliphatic structure in the char, and the increase in ordering in the aromatic structure (Fu et al., 2009). The inter-planar spacing of the two crystal lattices in chars decreased from 0.5 nm at 550ºC to 3.1 nm at 1,550ºC, indicating an increase in crystallinity as thermal transformation temperature increases.

The difference between coke and polymeric materials is the magnitude of the intermolecular forces and the capability of the individual chains to fit into a crystal lattice. For example, the intermolecular forces between the long chains in PP polymers have a tendency to align, creating a high degree of geometrical organisation, while in rubber they have a tendency to curl and fold, forming a highly disordered material. PP is a non-polar polymer and such materials are well known for having weak intermolecular forces between their chains, represented by Van der Waals dispersion.

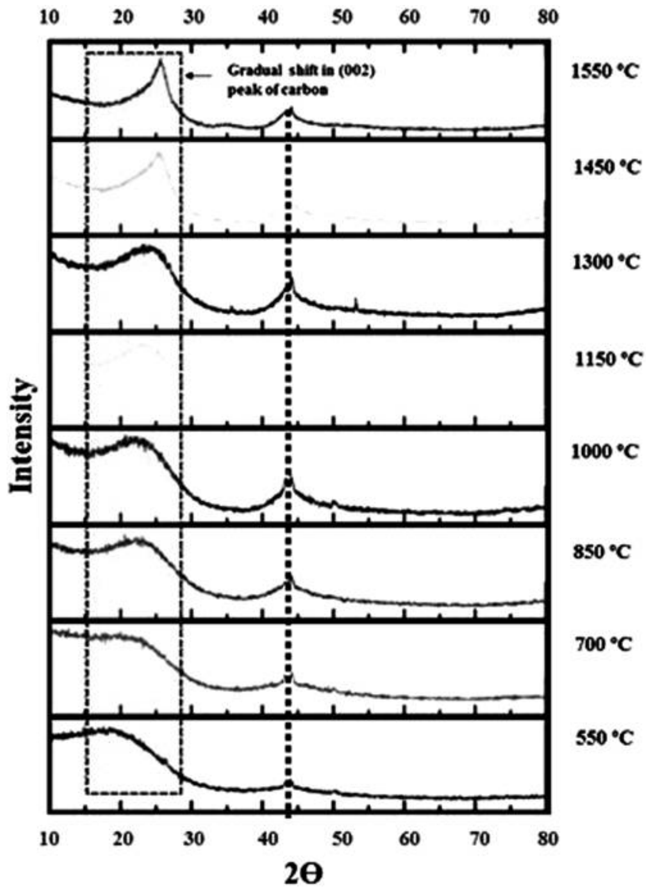

Fig. 15.7: Comparison of XRD Patterns of PC Residual Carbon at Different Temperatures. *Source*: Rajarao et al. (2014).

The temperature plays the decisive role at this point as it provides the energy to break the bonds; for example, 348 kJ/mol is needed to rupture the C–C bond and 413 kJ/mol is needed to break the C–H bond present in PP (Singh & Sharma, 2007). Coke has C=C bonds within the aromatic rings and the energy needed to break these bonds exceeds 1,000 kJ/mol. Hence, the mass loss is lower (higher residual mass) compared to the thermal transformation of blends involving PP proportions.

Based on their structure, polymeric materials will be transformed predominantly into either gas products or solid carbon during heat treatment. For example, PP and PU are transformed primarily into gas at high temperatures. However, a polymer such as PC generates an appreciable amount of residual carbon. It is worth noting that, based on the behaviour of polymeric materials, in terms of their transformation into gases or carbon, that they can be utilised in different areas of the pyrometallurgical processing of materials. The nature of the gases

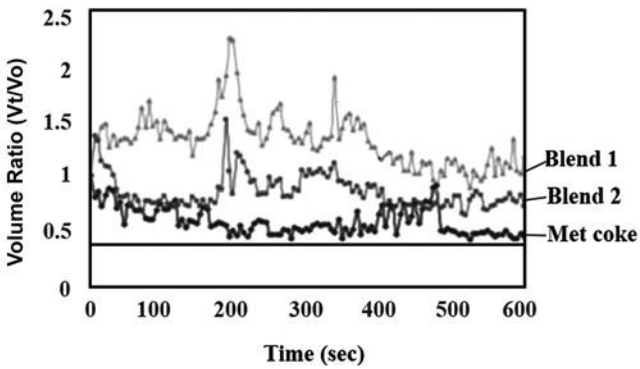

Fig. 15.8: Carbon/Slag Interaction for Metallurgical Coke/slag and Blend 1, Blend 2/Slag System at 1,550°C: Volume Ratio (V_t/V_0) as a Function of Time.
Source: With permission from Zaharia et al. (2009).

that are generated during the heat treatment of polymeric materials, along with the structure of the residual carbon, could play an important role in influencing materials processing, potentially providing technological benefits.

Waste Polymeric Materials and EAF Slag: Interfacial Phenomena

The reactions occurring at the slag/carbon interface were expected to be affected by the presence of the increased level of hydrocarbons in waste polymers compared to metallurgical coke, which could further decompose into carbon and hydrogen bearing products. In contact with an iron oxide rich EAF slag, the presence of iron oxide leads to a reduction reaction depending on the reducing agents, including C, CO and H_2, released at high temperatures. The carbon available in the carbonaceous substrate starts to react with the FeO from the slag. CO and CO_2 gases are formed and the slag droplet is inflated. The phenomenon of the entrapment and release of gases from the slag droplet depends upon a wide range of parameters including the rate of gas generation during the process of reduction.

The effect of gas generation – from the interaction between rubber/coke blends in different proportions (with blend #2 containing a higher amount of rubber) and slag – on the slag foaming phenomenon was studied. Fig. 15.8 illustrates the results of slag foaming for coke and blends 1 and 2 through V_t/V_0 versus reaction time. Gas generated during the process of reduction of coke and blends with slag is also shown in Fig. 15.9. The rate of gas generation increased when coke/rubber blends were used, when compared to coke alone.

It can be observed in Fig. 15.8, when the rubber proportion in the blend was increased, as in the case of blend 2, the volume ratio decreased compared to blend 1. It can be concluded that increasing the proportion of rubber in the blend improved slag foaming behaviour. However, this trend continued up to a particular proportion of rubber but, after that point, a higher proportion of rubber in the blend led to a relatively poorer slag foaming performance, as we see in the case

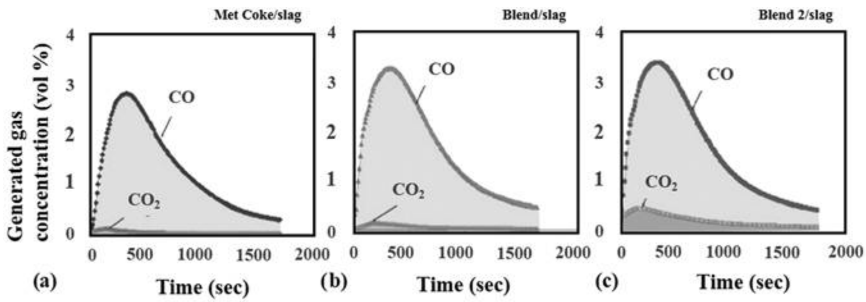

Fig. 15.9: Gas Generated as a Result of the Interaction of the Slag with Coke and Rubber-Coke Blends. *Source*: With permission from Zaharia et al. (2009).

of blend 2. This can be attributed to the higher gas flow rate from the coke/rubber blend (Fig. 15.9). Therefore, maintaining an ideal balance between the ratio of rubber and coke is essential to keep rates of gas generation at optimum levels.

The polymeric materials under investigation showed significant differences in gas generation and entrapment and subsequently in slag foaming behaviour. Metallurgical coke showed the lowest level of gas generation as well as the poorest slag foaming results; that is, foaming was not sustained over extended periods. Rubber blend 1 showed increased gas generation compared to coke and fluctuating behaviour with slag droplets increasing in size and then releasing gas. Blend PP had the highest level of gas generation compared to all the carbonaceous materials in this study and showed high initial slag volume. However, after this initial stage, the slag volume decreased within seconds and stabilised just above the volume ratio measured for coke/slag interactions.

In situ snap shots captured during specific times of reaction at 1,550°C, showed an increased volume when the carbonaceous material consisted of rubber blend 1 (Fig. 10b), while coke and PP showed similar slag droplet volumes (Fig. 15.10a and c) which are reflected in volume ratio results.

From these results, it can be interpreted that very high and very low rates of gas generation result in poor foaming behaviour. It is worth noting that not only gases which are generated from the transformation of polymers at high temperatures play a key role in slag foaming, but that the amount and structure of residual solid carbon is also important for the reduction of iron oxide. The chemical properties of the polymeric materials blended with coke have a significant effect on the rate and nature of gas generation, due to the breakdown of the polymer chains at high temperatures. Therefore, it is critical to blend polymeric materials and coke in appropriate proportions at which gases are not only generated at an optimum rate but in which sufficient carbon for reducing iron oxide is also provided.

Waste Polymeric Materials and Metal Interfacial Phenomena

The dissolution of carbon into iron is a key step in the manufacture of iron-carbon alloys. A number of investigations have focused on the dissolution behaviour

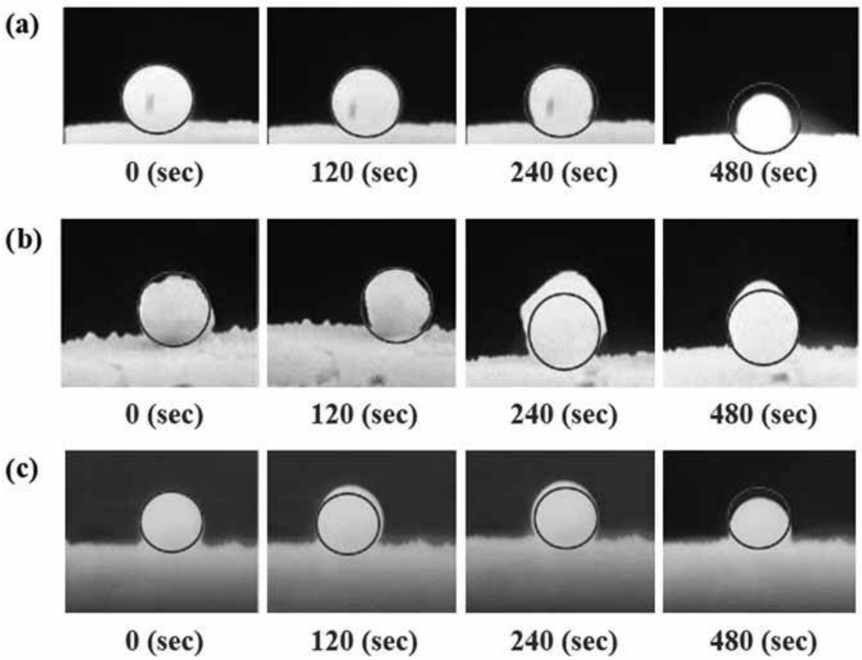

Fig. 15.10: Snap Shots of Slag Droplets in Contact with (a) 100 MC, (b) Blend R1 and (c) Blend PP at 1,550°C as a Function of Time. *Source*: With permission from Zaharia et al. (2010).

of graphite, coke and coal as carbon sources; however, a few studies have also reported on polymers (Kongkarat et al., 2011; Nath, Mansuri, Zaharia, Chaudhury, & Sahajwalla, 2012; Sahajwalla et al., 2012). Waste PC material was used in this work and carbon dissolution into liquid iron was investigated. Fifteen minutes of heat treatment of waste PC produced approximately 19 wt% char residue which was rich in carbon ~89%C.

Fig. 15.11(a) illustrates the concentration of carbon dissolved in iron at 1,550°C versus reaction time. The rate of carbon dissolution during the initial steps of reaction was very rapid; however, it slowed down as time passed. The total carbon level in molten iron reached a value of 4.21 wt% after two minutes of contact.

The first order rate constant for carbon dissolution was obtained using the following equations (Kongkarat, Koshy, O'Kane, & Sahajwalla, 2012):

$$\frac{dC}{dt} = \frac{Ak'}{V} \times \left(C_s - C_t\right)$$

$$\ln \frac{C_s - C_t}{\left(C_s - C_0\right)} = -K * t$$

where, C_s and C_t represent the saturation solubility and carbon concentration (wt%) in liquid iron, respectively. k' is the dissolution rate constant (m.s^{-1}) and A and V are the interfacial area of contact and the volume of iron droplet. C_0 is the initial carbon concentration in liquid metal. Fig. 15.11(b) shows the plot of $\ln \frac{C_s - C_t}{(C_s - C_0)}$ versus reaction time, and based on the slope of plot, the dissolution rate constant for PC carbon residue was determined to be 19.2×10^{-3} s^{-1} during the initial period of two minutes.

The wettability between the electrolytic pure iron and PC carbon residue substrate was studied using the sessile drop approach. The wetting image of the liquid melt on the solid substrate was monitored and recorded continuously by CCD camera. These recorded images were converted to individual images for contact angle measurement.

The wetting experiment was also carried out using the measurement of contact angle between the substrate and molten iron. Fig. 15.12 shows the contact angle between the PC carbon residue substrate and molten iron during the initial reaction time from 0 to 10 seconds. A small decrease in the contact angle was observed from 79° to 70°, which could be attributed to the transfer of carbon and a change in interfacial energy due to the interaction between carbon and molten iron. Later, an increase was also observed in contact angles that reached 100º

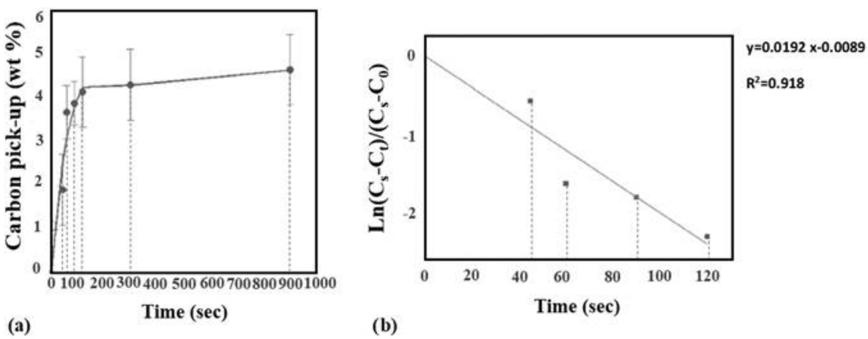

Fig. 15.11: (a) Variation in Carbon Pickup from PC Carbon Residue by Molten Iron at 1,550°C Versus Time, (b) Plot of $\ln((C_s - C_t)/(C_s - C_0))$ Versus Time. *Source*: Mansuri, Khanna, Rajarao, and Sahajwalla, 2013).

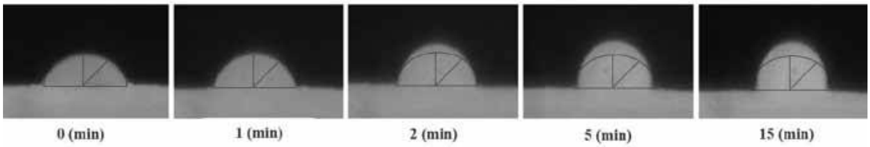

Fig. 15.12: In situ Images of PC Carbon Residue Substrate in Contact with Molten Iron as a Function of Time. *Source*: Mansuri et al. 2013.

after 3 minutes and stabilised at 105° after 15 minutes, thereby indicating much poorer wetting as the carbon level in molten iron approaches saturation.

It is well known that the dissolution of carbon into molten iron occurs through different steps. First, carbon atoms become dissociated from the host lattice and transfer to the carbon/iron interfacial region and pass through the interfacial boundary layer into the bulk iron. The high dissolution rate of carbon from PC carbon residue compared to other carbonaceous materials such as coke could be attributed to the absence of blocking elements coming from ash at the interfacial region between the iron and char substrate. Therefore, carbon atoms faced minimal resistance while they were penetrating the facial region of carbon and iron. Good wetting behaviour, particularly at the initial stages of reduction, could be an indication that no ash layer was present at the interfacial region of char and carbon that resulted in better carbon dissolution. The minor increase in the contact angle during the final stages of reaction is due to the increasing carbon level in molten iron.

In another work, we have published (Assadi & Sahajwalla, 2014), by using ab initio molecular dynamics simulation, we demonstrated that the hydrogen content of PCs does not dissolve in molten iron but rather escapes in gaseous form. We also published work that demonstrated the production of nano-structured graphitic materials from (Nath et al., 2012) end-of-life kitchen melamine-formaldehyde (MF) plates, using heat treatment techniques at 1,600°C under nitrogen flow of 2 L/min. The synthesised graphitic material was used as a carburizer material in reaction with iron pellets. After a 45-minute reaction time the carbon content in the iron pellet reached 5.65%, which is quite low compared to the result obtained for waste PC (4.12% carbon within two minutes). The difference in the behaviour of waste PC and MF as carburizer materials could be attributed to their different structures. The level of crystallinity in graphitic material which was synthesised by MF was low compared to waste PC. About 30% of the synthesised graphitic material from MF remained amorphous which affected the carburizing process. These comparisons clearly confirm that the structure of graphitic materials synthesised from waste polymers – or any other end-of-life products – has a dominant influence on the carburizing process.

Industrial Implementation

Arrium, formerly OneSteel, an Australian-based steel manufacturer, has been actively developing innovative processing technologies to utilise waste materials such as end-of-life tyres and post-consumer plastics as an alternative carbon unit in EAF steelmaking. In close co-operation with the SMaRT Centre, University of New South Wales, Arrium developed and commercialised *PIT*, which enables EAFs to inject a blend of coke and rubber in place of coke, resulting in improved slag foaming and hence furnace efficiency. Arrium has been using *PIT* as a standard practice since 2008 at its Sydney Steel Mill (SSM) and Laverton Steel Mill (LSM) in more than 92,710 heats, consuming over 2.6 million recycled tyres in the process. *PIT* has been granted patent protection in most major industrial countries and it has been commercially implemented at UMC Metals, Thailand,

Table 15.3: Summary of the Benefits of Using PIT.

Benefit Area	Reduction in Electrical Consumption (KWh per Billet Tonne) (%)	Reduction in Inject Carbon (Kilograms per Heat) (%)	FeO% Reduction in Slag (%)	Yield Improvement (%)
SSM	2.8	12.0	3.0	0.30
LSM	2.4	16.2	2.5	0.27
USA Trial	1.7	6.3	2.4	0.24
Asia 1	5.1	12.0	2.0	0.20
Asia 2	3.8	12.0	—	—
Europe 1	1.6	8.4	1.5	0.17
Europe 2 Consteel	2.1	7.2	—	—

since May 2011, at SeAH Besteel, Korea, since April 2014, at Celsa Group's plant in Cardiff, UK, since October 2014 and at Celsa Nordic in Norway since December 2015.

The benefits of using *PIT*, which were statistically proven during the commercial implementation trials on each site, are listed in Table 15.3 (Maroufi et al., 2016). This innovation offered an excellent opportunity to improve furnace efficiency with a positive impact on the environment through energy savings and the transformation of a major global waste stream into value added products.

As it can be seen, the incorporation of *PIT* into Arrium's commercial operations has achieved a 12.0 and 16.2% reduction in inject carbon in SSM and LSM, respectively. The incorporation of *PIT* has also resulted in saving energy through a reduction in electrical consumption, which was reported as 2.8 and 2.4% for SSM and LSM, respectively. The technology of waste polymer injection has also improved the yield of furnaces by about 0.3 and 0.27% in SSM and LSM, respectively.

The incorporation of *PIT* also improves the foaminess of the slag, and therefore, furnace efficiency. The foaming slag phenomenon in the EAF is known to be an important feature which reduces the cost of energy, improves furnace efficiency and stability while reducing the sound, vibration and electrode consumption during the process of iron melting (Sahajwalla, Hong et al., 2005). Thus, an understanding of the relationship between the physicochemical properties of slag and its foaming behaviour is of great significance due to the considerable effect of slag on the foaming phenomenon.

Conclusion

ASR has been characterised detecting a range of different polymers including PP, PC and rubber. Given that rubber, PP and PC were found to be components of ASR, these polymers were selected in this work. The study aimed to demonstrate the potential use of these end-of-life polymeric materials, as rich sources of carbon and hydrogen, in different areas of pyrometallurgical processes.

PP and rubber blended with metallurgical coke were studied in reaction with industrial slag. Waste PC was used as a carburizer material in reaction with iron and the dissolution rate of carbon from PC char into molten iron at 1,550°C was measured.

Experimental results indicated that when coke-polymer blends were used as sources of carbon in reaction with slags, the rate of gas generation increased due to the removal of volatile materials along with gas produced from reduction.

A very high rate of gas generation during the process of reduction lead to a fast escape of gas from the slag droplets, and poor foaming behaviour. A very low rate of gas generation also had a negative effect on slag foaming. Therefore, it is critical to blend polymeric materials and coke in appropriate proportions to ensure that gases are generated at an optimum rate *and* that a sufficient amount of carbon for reducing iron oxide is provided. In fact, the optimum proportions of polymers in blend with metallurgical coke, as carbonaceous materials, in reaction with slag results in improving slag foaming behaviour.

The thermal transformation of waste PC produced ~19 wt% residue with high content of carbon ~89 wt%.

The high dissolution rate of carbon from waste PC char into molten iron, and carbon pick up of 4.21 wt% C in 2 minutes reaction time, confirmed that this type of waste polymer could be considered as a carburizing material.

Although only a few of the possibilities have been outlined here, our range of research projects suggests that the potential for using waste as raw materials for industrial production is significant.

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Chapter 16

Towards an Agile Circular Economy for the Building Industry

Tim McGinley

Abstract

The circular economy (CE) requires that 'used' materials continue to be in circulation after their initial use has finished. Materials are typically sourced in the building industry as new materials in bulk that carry guarantees of safety, quality and delivery. The distributed and diverse origins of used materials mean that they do not normally carry these guarantees. Furthermore, existing potential procurement systems for reused materials such as eBay allow users to present their auctions in a loosely structured form that can make it difficult to manage and procure multiple items to satisfy the quantities, condition and type required by the contractor. Therefore, this chapter proposes an information system to support the agile procurement of used materials at a scale that is appropriate for construction projects to support the CE. It describes the development of a tool called 'JunkUp' that would allow multiple auctions of similar items from diverse sellers to be managed as a single item. Based on this system, in future work, it should be possible to use this tool to test strategies to address the risk to safety, quality and delivery of reused materials in construction. This should ultimately lead to the opportunity to increase material reuse (and reduce waste) in the building and construction sector and support an agile CE for the building industry.

Keywords: Waste informatics; building information modelling; reverse logistics; Industry Foundation Classes; agile design methods; JunkUp tool; E-procurement; architectural salvage; eBay

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 281–294

doi:10.1108/978-1-78714-619-820181022

Introduction

Despite an increasing global awareness of resource scarcity, the building industry still uses a large majority of new materials in construction projects. An alternative approach would be for it to source used materials. This would reduce the amount of waste going to landfill. However, the use of reclaimed materials has traditionally been unattractive to the building industry because new materials can be ordered in bulk and carry guarantees of safety, quality and delivery. The circular economy (CE), 'promises to overcome the contradiction between economic and environmental prosperity' (Pomponi & Moncaster, 2017). From a logistics perspective, the reuse of materials has been referred to as 'reverse logistics' (Barros, Dekker, & Scholten, 1998). Services such as eBay provide methods for consumers to purchase new and used products for building projects from both businesses and individual consumers by specifying eBay categories such as 'building products/DIY'. In eBay, it is possible to purchase building products and specify the quantity required as well as query the dimensions of the available tools. It is also possible to specify the 'condition' of the product.

The construction industry is currently going through organisational change due to the implications of implementing building information modelling (BIM) which ultimately promises an information model for the building that includes every material in the building. The current process of searching on eBay for individual items and separately arranging the logistics for each item is suitable to the self-builder, but may not be appropriate in medium and large construction projects, which are more likely to favour information-rich (virgin) material supply chains over the ad hoc item information provided by eBay for used materials.

Agile design methods, originating in software development practices, have previously been applied in architecture to support flexible or 'agile' design development (McGinley et al., 2017). As an extension to this work, this chapter proposes an 'agile' approach to material procurement by potentially enabling materials for each element of the building to be sourced independently from waste, recycled or virgin channels. The chapter proposes the creation of an 'agile' material system and accompanying digital tool that can be used to search for BIM specified materials on eBay. This would enable project managers and architects to update building material choices in real time in response to changes in supply chain availability of virgin materials, ultimately supporting the implementation of the CE through the procurement of waste materials into the construction of new buildings.

To achieve this, it is necessary to propose an information model that uses terms that are relevant to the construction industry and could be used to search databases of materials such as eBay. Based on this model, a tool would be developed to query BIM materials in eBay's databases. In future work, this could be extended to the development of a web/mobile phone app that could automatically bid and arrange delivery of items within a defined geographical radius of the building site. This would enable a software 'bot' linked to a CAD program such as REVIT through a plugin to propose local salvaged materials for a building, updating the current bidding cost and availability of the items in real time. The following section explores previous approaches to this challenge.

Background

The architecture practice Superuse Studio (Jongert, 2015) describes reusing materials as 'harvesting' waste materials. In two projects in the Netherlands, Superuse Studio used reclaimed materials to create challenging architecture including Worm, a cultural institution in Rotterdam and espressobar *K, a coffee shop/space station in the foyer of the TU Delft architecture department. Both examples were made from reused materials. espressobar *K used reclaimed airplane seats, washing machine doors and many other materials, whilst Worm featured toilet cubicles made from septic tanks. Whilst it is practical to source used materials for bespoke projects, we rarely see this kind of approach in larger construction projects. Moreover, the real benefits of a shift to a CE can only be realised if the methods can be scaled to global supply chains (Ellen MacArthur Foundation, 2014).

The transition to a CE requires integration of information systems (Velte & Steinhilper, 2016). The dominant information system in the construction industry is BIM. There is an interest in this industry in the implications of BIM in electronic procurement (e-procurement) for the 'quantity take off' stage, providing efficiencies in cost estimating in large construction projects (Ren, Skibniewski, & Jiang, 2012). It is possible to imagine that projects that implement BIM can handle greater complexity and could support increased risk using the e-procurement of materials in the construction industry. It is, therefore, possible that this could enable improved support for used materials. The challenge is that used materials typically do not have the informational assets required by BIM technologies to achieve their proposed optimisations. At the same time, the construction industry is still behind other industries in terms of e-procurement. However, Grilo and Jardim-Goncalves (2011) argue that Model-Driven Architecture, Service Oriented Architecture and Cloud Computing offer solutions from computer science to bring the AEC industry up to speed (Jardim-Goncalves & Grilo, 2010). Although, even with the implementation of these technologies, BIM uptake has its own organisational, legal and technical challenges (Rezgui, Beach, & Rana, 2013).

Looking at the problem from the end of a building's lifecycle, Cheng and Ma (2013) propose a method to use BIM to help the construction and demolition industry to make recyclers aware of the type and volume of material in a building prior to demolition. It is therefore possible that such BIM enabled waste could be reused in new construction. Whilst this is appealing, it does not help with the existing non-BIM used construction material that is potentially available to construction projects. Dankers, Geel, and Segers (2014) report that BIM implemented in a web platform with an open standard such as Industry Foundation Classes (IFC) which links to external sources could be used to support the lifecycle management of materials in buildings. IFC provides an independent data format to support the sharing of building and material information in the building and construction industry. IFC is used as the basis for OpenBIM (OpenBIM, 2015). IFC has many classes for dealing with materials. OpenBIM has been used in a variety of contexts, including supporting cost estimation in early stage building design (Choi, Kim, & Kim, 2015).

Agile Material Systems

Traditional material supply for virgin materials are designed to be stable. One of the challenges of incorporating used materials from demolitions into the design of new buildings, for instance, is that these may involve ad hoc procurements. This means that material supplies can be difficult to predict and may require extensive design changes to accommodate them. Unfortunately, the traditional waterfall design process requires decisions about materials to be 'locked in' early on in the design process. This means that material-specific design decisions are embedded into the design of the architecture and that a change to the materials would result in very expensive changes to the design. Materials are selected and embedded into the design of the project, but even with a full BIM model, it is not possible to query the design intent for that material. This matters because if we should find that that material is no longer available, it will be difficult to ascertain an appropriate alternative material. Agile design for architecture proposes an alternative approach wherein decisions about materials are decoupled from the design decisions (Fig. 16.1).

Ideally, the design, material and fabrication/construction system for the building should be 'decoupled' to allow for dynamic changes to occur in the design process. Collectively, these systems make up Agile 'X' systems (McGinley, 2015; McGinley et al., 2017). An agile design process for architecture enables the separation of the information systems of the design from the specification of their material manifestation. In this way, the chapter provides an alternative conceptualisation of building information systems to support the CE. Fig 16.1 describes how the decoupled system, following agile fabrication principles, remains flexible for longer than the coupled system.

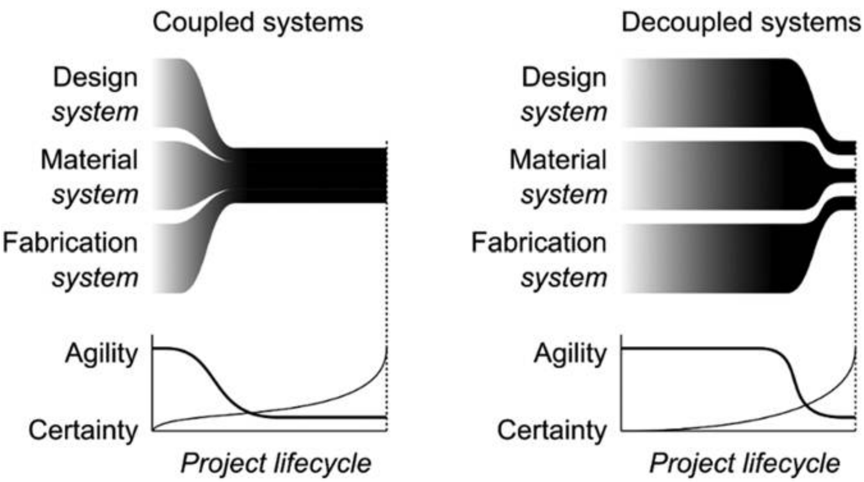

Fig. 16.1: Comparison of Coupled and Decoupled Systems.
Source: McGinley, 2015.

Agile X Framework

It has been mentioned that the CE requires greater flexibility in the design process to adapt material decisions during the course of the design. In information architecture, systems are typically depicted as layers in an architectural diagram that implies that these layers are stacked on top of each other and information flows downstream in the process. In order to apply this idea into architecture, in addition to the design, material and fabrication system, we have proposed an 'architectural framework' (in a computer science sense) that provides a template for an agile design system. Architecture frameworks are frequently used to model information in enterprises, although they have not previously been used to model buildings (McGinley, 2015). The Agile X framework defines a simplified architecture framework that would enable us to know which elements were fixed and which could change. The design team can then add, change and remove design, material and fabrication systems without detriment to the realisation of the building.

Agile Design Layer

In the example of this chapter, the design layer describes the design of the building. This could be based on typological templates that can be placed onto sites either virtually or physically and displayed to the designer to capture the design decisions that they apply on top of them. The design layer does not determine the materiality of the architecture; this is defined in the material layer in the following section.

Agile Material Layer

This layer describes the 'matter' of the architecture; what the building is made of which is 'agile', and through which this chapter addresses the concerns of the CE. An example of this can be seen in an architectural pavilion we completed recently, in which we left the specification of the material for the pavilion to the very last moment. We had settled on an opaque material but then it became apparent that part of the structure needed to be transparent.

Due to the flexibility of the system, we were able to swap in an alternative material and apply it to the design system without any delay to the project. It was also helpful as it enabled us to build a 1:6 model of the pavilion to check any potential problems with its development.

Agile Fabrication Layer

Similarly, the pavilion shown above could have been fabricated in a variety of ways, although CNC milling, water jet-cutting or laser cutter depending on the material file. This layer would need to be compatible with the material file (Fig. 16.2).

Fig. 16.2: The Pavilion Project Showing the Result of the Two Different Material Systems.

Method

It is clear that the diverse and unpredictable nature of used materials makes it challenging to source and incorporate used materials at scale and not lose the advantages that BIM offers. Therefore, this chapter proposes an agile material systems file that could be used by an app to query eBay's databases for used construction materials. This involves the development of two artefacts, the material file and the tool to support the information system. Hevner and Chatterjee (2004) propose the use of design science to develop information systems. Additionally, Peffers, Tuunanen, and Rothenberger (2008) propose a design science methodology for developing information systems which can be defined in the following stages: problem identification and motivation; definition of solution objectives; design and development; demonstration; evaluation and finally communication. The problem identification stage has been established in the previous sections. The evaluation stage represents the discussion stage and the communication stage is this chapter. The remaining stages are addressed in the following sections.

Solution Objectives

This chapter identifies an approach to support the procurement of used materials from diverse sources as a viable alternative to the procurement of new material from a single supplier in the building and construction industry. We focus on supporting the user to identify salvaged building material using eBay's product database, at a scale that is appropriate to medium-size construction projects. The background identified that the IFC standard enables an 'open BIM' standard that supports data interoperability between traditional stakeholders in the buildings industry. However, eBay is built to describe a lots of different items and does not follow BIM standards in its description of items in its building materials/ DIY category. Therefore, this chapter proposes the development of a schema to link IFC and eBay using the eBay Application programming interface (API). The challenges involved in this work will be identified in this section. Some of these will be addressed in this work and the remainder will be highlighted for future work. This will require the identification of a material schema modelled on common concepts between the IFC BIM standard and eBay's existing product definitions that enables the user to identify materials in a different digital environment, such as a CAD package. This requires that the user can *Aggregate a specified quantity, condition and type of material from multiple eBay auctions in one event.*

Therefore, this chapter proposes the creation of an agile material file which supports both IFC and eBay terms. The term *agile* is used to represent that the file can represent different types and conditions of material. This file will be tested by developing a web application that uses eBay's API and the agile material file to identify salvaged materials at a scale appropriate for construction projects. The following section describes the stage to develop a tool to address the identified requirements.

Design and Development

The web application needs to work with the agile material schema which in turn should be relevant for both the IFC BIM standard and the eBay API terms. For the tool, eBay provides an API that allows software developers to produce software that makes use of eBay's databases. This should offer the opportunity to source building material from eBay. The tasks involved are captured first in a use case diagram (Fig. 16.3) for sourcing used materials on eBay from multiple

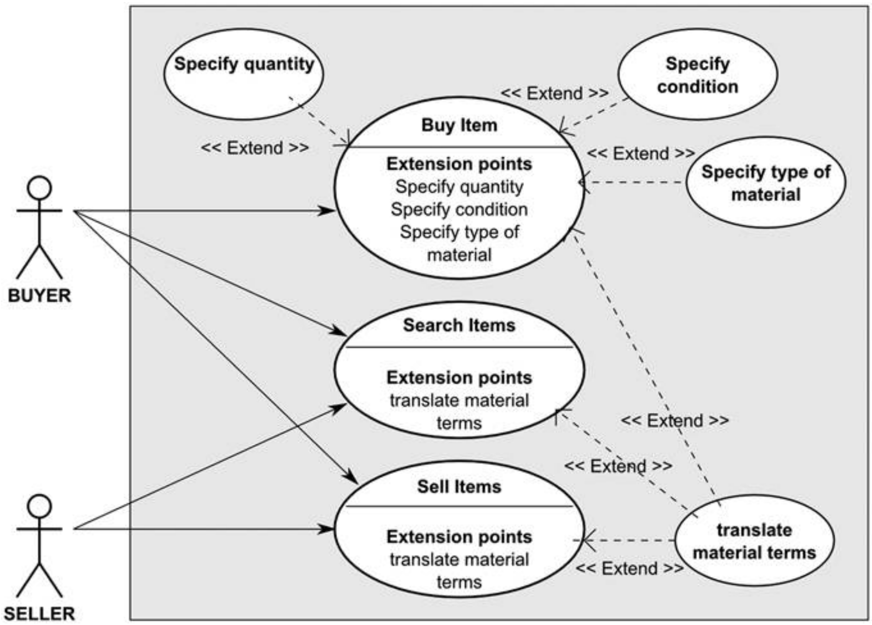

Fig. 16.3: Use Case Diagram for the JunkUp Tool.

Table 16.1: User Requirements Based on the Use Case Diagram.

User	Requirements
Buyer	Capacity to specify the quantity of material required and query the eBay database for the required material (may require multiple auctions).
Seller	Uploads the item to eBay using standard interface and eBay terms.

auctions in one transaction. The tasks in the use case diagram (Fig. 16.3) are translated into user requirements for each of the users (Table 16.1).

This presents several technical and practical challenges including how to capture and 'translate' eBay's existing material descriptions to enable designers to source material from eBay. To address this an agile material (translation) file is proposed in the following sections to enable the easy uploading of salvaged material to eBay and the easy recall of this data from inside (or close to) the designers' CAD package. OpenBIM provides an 'xBIM API' to enable developers to produce software that is in line with the OpenBIM standards. It was not possible to fully integrate the xBIM API into this iteration of the research, but this is included in future research plans. The proposed tool application will be called 'JunkUp' to emphasise and question the waste status of 'upcycling' materials.

IFC Concepts

For the material file, one approach to address this is to produce an 'entity relationship diagram' that describes the relationship between concepts (entities) in a database. This should include concepts from BIM and eBay. The IFC Classes ifcMaterialLayer and ifcMaterial are therefore relevant to an approach to identify a standard material file that could be read by the app. These classes and their attributes are described in Fig. 16.4.

The material system file will need to contain attributes that are of interest to the designer, including the extensive values of depth, height and width as well as material type. The following section identifies the eBay specific concepts for the agile material file.

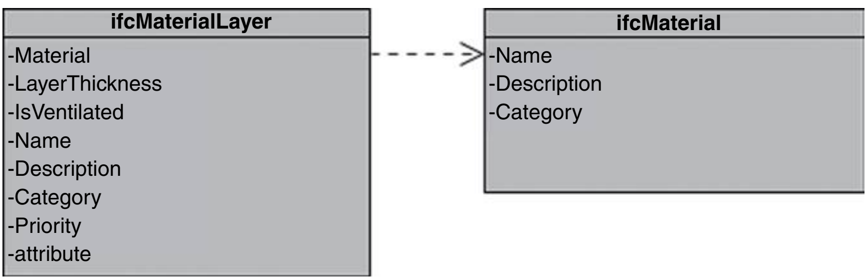

Fig. 16.4: Material Definitions in Industry Foundation Classes (IFC).

eBay Concepts

eBay is instructive for helping to investigate the concept of new and used. Whilst as a consumer we frequently see used or new or 'brand new in box' as a description, different categories describe new or 'usedness' differently. To get around this, eBay uses a conditionID value from 1,000 to 7,000 (eBay, 2015). Building materials generally fit into the business and industrial category, and therefore map to the typical eBay conditionID names.

Mapping the Concepts

The previous two sections identified the component concepts of the agile material file. In response to this, *Table* 16.2 attempts to map key concepts from the IFC standard and eBay API (eBay, 2015) to common material concepts using an entity relationship diagram. This provides the relationship between the concepts as well as their attributes. In this way, the IFC standard and eBay API provide a standardised set of concepts (entities) that the agile material system could employ. *Table* 16.2 (below) shows that some concepts are shared across the domains of BIM and eBay. The condition concept would be important in a construction context and future work will attempt to identify a non-destructive method of testing the artefacts before they go into the construction of the building.

Table 16.2: eBay API Definitions for Item Condition.

ConditionID	**Typical Name**	**Cameras and Photo, Cell Phones and PDAs, Computer and Networking, Electronics, Business and Industrial, Home and Garden, Musical Instruments**
1000	New	New
1500	New other (see details)	New other (see details)
1750	New with defects	
2000	Manufacturer refurbished	Manufacturer refurbished
2500	Seller refurbished	Seller refurbished
3000	Used	Used
4000	Very good	
5000	Good	
6000	Acceptable	
7000	For parts or not working	

Source: eBay (2015).

Demonstration

The tool is still in development and so no user testing has been carried out at this stage. However, the proof of concept demonstrated that it was possible to establish links between the IFC and eBay concepts, and that these could be developed into tools that the design and construction team could use in the future.

Discussion

The previous section demonstrated that it was possible to map some of the terms from IFC to the eBay API. The method specified the following solution objective: *Aggregate a specified quantity, condition and type of material from multiple eBay auctions in one event.*

The mockup's ability to satisfy the elements of this objective are discussed in the following section. These are reviewed through the embedded links to the top three search results (Fig. 16.5, above).

Specified Quantity

It would be possible to specify a specific quantity of the items on offer. However, it is more challenging to specify a square metre age of material, for instance, due to the textual descriptions on the page or in the title, rather than users typically inputting the length, width and depth/thickness of the material as discrete values in the auction (Fig. 16.6).

Specified Condition

This factor was employed in the original API call:

&itemFilter.name=Condition&itemFilter.value=3000.

This was successful in limiting the search results to those that specified 'used' in their listing. However, it is unclear if listing giving different conditionID (Table 16.3) would have been missed off the search results.

Specified Type

A specific type was not called in this case, such as a material, or listing category, as the use of key words is quite effective in identifying building products and general category types, such as 'building material/DIY', and so do not help to reduce the number of results in the filter. However, in future work, the effect of category and material filters and their relationship to their IFC analogues should be investigated in more detail. A limitation of this work is the current reliance on cuboid dimensions that may not represent the 'form' of the material. Along with this there are syntactical challenges in the way that the materials are

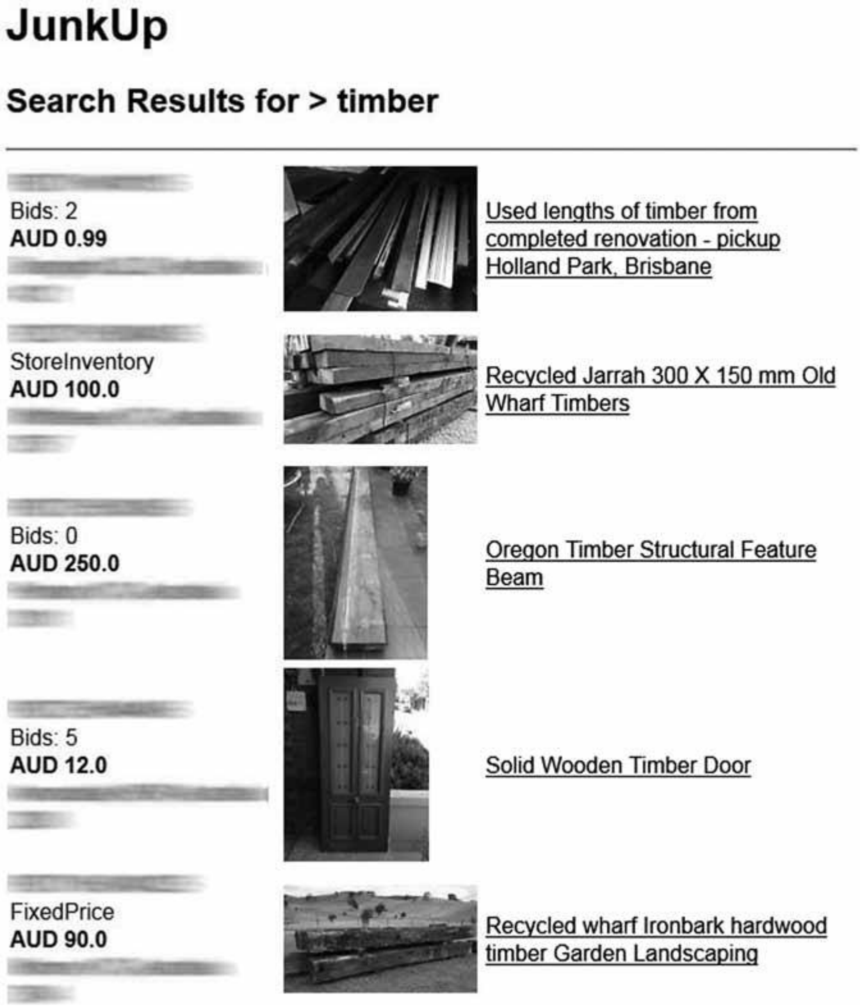

Fig. 16.5: Shows the Limited Functionality of the Program that Links eBay API and IFC.

to be described on a system such as eBay. One approach to address the challenges, with the ever-decreasing cost of LIDAR and 3D scanning technologies, would be for the seller to scan the item and for this digital model of the item to be included with the item. In the same way that eBay currently offers users prefilled values for known items it could be linked to a 3D model database, such as that provided by Trimble (formerly, owned by Google) with its 3d Warehouse (Trimble, 2015) technology.

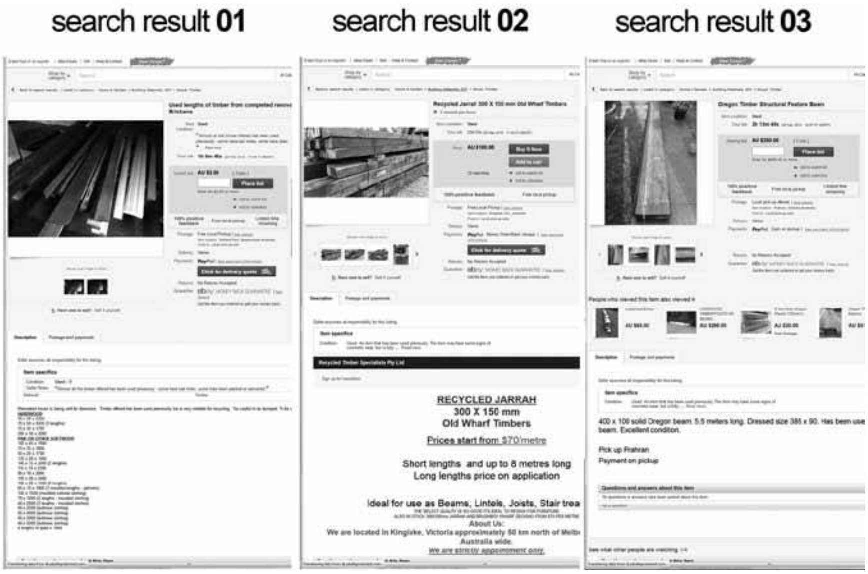

Fig. 16.6: Data Representation in the Top Three Search Results from the JunkUp App.

Table 16.3: Agile Material File Concepts.

Concept	ifcMaterialLayer	ifcMaterial	eBay API
Name	Name		Name
Category	Category		?
ProductType	Material	Name	
Description	Description		
Thickness	LayerThickness		?
Length	?		PackageLength
Width	?		PackageWidth
Depth	?		PackageDepth
Quantity	?		Quantity
Condition			ConditionID
Location			Location

Conclusion

The main limitation of the research described in this chapter is that it was not tested in the field. However, the aim of this project was not to develop the app, but to propose an agile material system that could support the procurement of used materials from eBay from a variety of sellers at scale. Future work should investigate the potential for a JunkUp seller's tool for sellers to easily post items that include terms that would be relevant to the construction industry. These terms could possibly be a line of human readable code that could be read by the JunkUp buyer app appended to a standard description. It may also be appropriate to develop an app using eBay's seller API which would enable users to input Agile X specific information into the eBay listing.

Ultimately these tools should link to a digital design environment such as REVIT that can arrange the search results into a 'super' component containing individual eBay items that could form a wall, slab or roof item in a CAD program using the IFC schema. This should also be able to identify material clashes and propose the necessary joints and cuts. This future work will be supported by the 'agile' material file format proposed here to enable contractors to source salvaged material with minimum risk to the project from automated third person services such as eBay. Based on the evaluation of the tools in this chapter, the availability of additional APIs such as xBIM's open source BIM development API and eBay's API appear to be appropriate technology candidates for this important work to support the CE.

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Chapter 17

Research on the Sustainable Water Recycling System at Tianjin University's New Campus

Sen Peng, Huiping Cui and Min Ji

Abstract

The new campus of Tianjin University was designed, built and now operates following a green and sustainable concept. The campus' eco-friendly water environment was formed by establishing a water recycling system. The campus is divided into three drainage sections based on the masterplan. Each drainage section adopts different methods of collecting, utilizing and discharging water according to specific conditions, aimed at achieving both high drainage capability and the efficient utilisation of rainwater. The campus was designed so runoff pollution is reduced through the utilisation of low-impact development methods, ensuring the quality of the recharge water. Through studying the fundamentals of treatment measures and models for simulating water quality, water circulation, constructed wetlands and pollution control of rain runoff, parameters for efficient water recycling could be mathematically forecast, ensuring that stakeholders can be continuously engaged in improving and preserving the water quality of landscaped water on campus. The overall system integrates a variety of measures being implemented into one cohesive entity, which contributes to establishing the sustainable and healthy water cycling system of the green campus.

Keywords: Sustainability; rainwater collection and utilisation; low-impact development; water cycling; green campus

Introduction

Tianjin University is a national key university under the direct administration of the Ministry of Education of China. The construction of Tianjin University's new

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doi:10.1108/978-1-78714-619-820181023

campus, Peiyang Campus, was finished in 2015. The new campus was designed, built and now operates following a 'green' and 'sustainable' concept.

The water environment system, as a special infrastructure for flood control, drainage, local climate adjustment and landscape beautification, is an important component of the campus environmental system. However, in northern China, in cities such as Tianjin, shortages of water and the deterioration of surface water quality have been serious problems in the operation and management of water environment systems. On the one hand, as water resources become scarce, surface water such as urban landscaped water is often supplemented by rainwater collected by rainwater systems. There has been a lot of study on rainwater harvesting and utilisation systems over the past few years.

Research indicates that rainwater harvesting can play an important role in local and regional hydrological cycles (Nachshona, Netzerb, & Livshitz, 2016). Palla, Gnecco, and La Barbera (2017) analysed the influence of domestic rainwater harvesting systems on storm water runoff control by using hydrologic-hydraulic modelling and a high-resolution rainfall data series from a residential urban block test site. The collected rainwater can also be used for low-demand applications such as the washing of vehicles and other equipment, cleaning outside concrete and the watering of green areas, and this can save a large amount of fresh water (Sanches Fernandes, Terêncio, & Pacheco, 2015). Jing, Zhang, Zhang, and Wang (2017) developed a computational model based on a water balance equation to assess rainwater harvesting, water-saving efficiency and the economic viability of rainwater harvesting systems in eight cities across four climatic zones of China, indicating that storm water capture efficiency could differ with the variety of water demand scenarios and climatic zones. The potential use of rainwater harvesting and utilisation effectiveness was analysed and compared for sustainable water management practice in highly urbanised cities such as Hong Kong and Tokyo, using Geographic Information System (GIS) and the ENVI-met model (An, Lam, Hao, Morakinyo, & Furumai, 2015). Rainwater utilisation has become an important component in the sponge city construction initiatives across China. Technical guidelines for sponge city construction in Tianjin promulgated by the city government recommended rainwater utilisation as a necessary water supplement method in new constructions in the urban area (Tianjin Urban and Rural Construction Commission, 2016).

On the other hand, rainwater harvesting can introduce diffused pollution into the receiving water body and has a significant influence on surface water quality in northern China (Li, Ma, Yang, & Inchio, 2011). The Water Pollution Control Action Plan of China with regard to the treatment of non-point source pollution, such as runoff pollution, as an important component of water pollution prevention and control (Ministry of Environmental Protection of China, 2015). Therefore, it is necessary to combine rainwater collection and utilisation, rainfall runoff pollution control and landscape water quality conservation to ensure sustainable water quality management.

In the planning, construction and operation of the new campus of Tianjin University, the eco-friendly water environment of the campus was formed by establishing a sustainable water recycling system for the green campus. Tianjin University took ecological rainwater utilisation and integrated water quality conservation methods, and applied them in a breakthrough attempt to realise a sustainable water cycling system for both water resource management and aspects of water quality assurance. This planned utilisation of rainwater reduces landscaped water replenishment costs, which allows managers of the water bodies to invest more resources in maintaining water quality. This sustainable water system helped establish the circular economy of the campus, and ensured its sustainable development during construction.

Rainwater Discharge System Planning for the Green Campus

Campus Profile

Tianjin University's new campus covers an area of 2.5 square kilometres. The total watershed area of the new campus is 154,000 square metres, including a landscaped central lake, landscaped river, an overflow lake and a constructed wetland. The storm water discharge system is designed as a multisection discharge system divided into the central island area of 292,800 square metres, the middle pipeline area of 856,700 square metres and the outer ring discharging area of 923,900 square metres (Fig. 17.1).

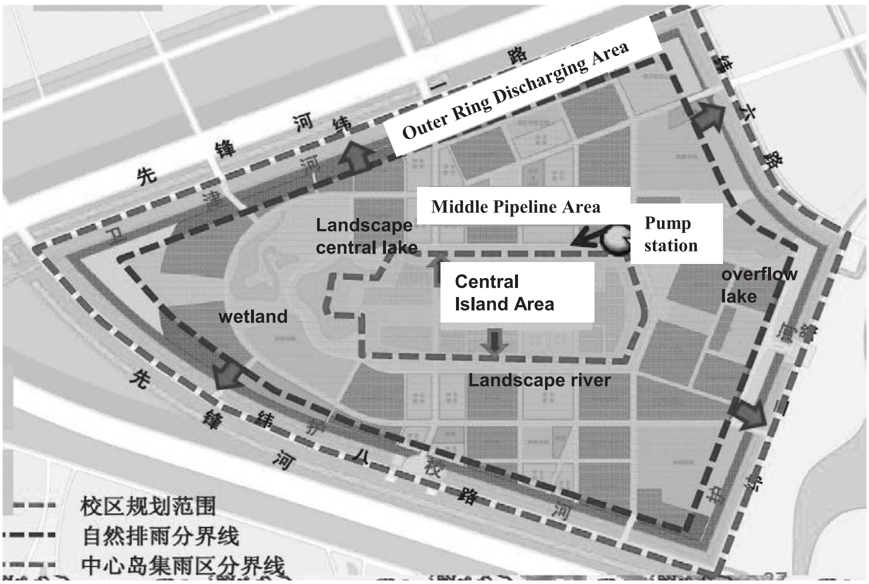

Fig. 17.1: Surface Area and Discharging Layout of the Campus.

Framework of the Multisection Discharge System

The campus storm water utilisation and discharging system focuses on both flood discharging and rainwater utilisation, building a multisection rainwater collecting, utilizing and discharging system. The major rainwater collection system of the campus stores up and infiltrates rainwater for supplementing the water required for the landscape design.

The Central Island Rainwater Eco-Collection Area

This area is within the outer ring rainwater discharging area, except for the middle pipeline rainwater collection area, and covers an area of 292,800 square metres. Following the principles of eco-collecting, source-cutting, flood-control and self-purification, this area demonstrates how such a new integrated rainwater eco-collection system can be compatible with the environment.

The Middle Pipeline Rainwater Collection Area

This area is situated outside the landscaped water area and covers a total of 856,700 square metres. The rainwater in this area is collected by the pipeline and is used to supplement the landscaped water used within the campus. The surplus rainwater is injected into the Weijin River through a pump station, which combines traditional rainwater collection methods with the campus's ecological rainwater utilisation concept.

The Outer Ring Rainwater Discharging Area

The outer ring rainwater discharging area is defined by the surrounding area of the campus within the city's green belt, with an area of 923,900 square metres. The rainwater in this outer ring rainwater discharging area is discharged into the Weijin River by the surface facility. The outer rainwater discharging area ensures safe floodwater discharge so as to better manage storm water flows within the campus (Fig. 17.2).

Storm Water Utilisation System

Planning and Construction of the Storm Water Utilisation System

The overall planning of the rainwater utilisation system was centred on the Central Island Rainwater Eco-Collection Area and the Middle Pipeline Rainwater Collection Area.

Rainwater Utilisation Methods in the Central Island Rainwater Eco-Collection Area

Applying the green campus concept to the realities of construction on campus, access to technologies and financial and management factors, the central island

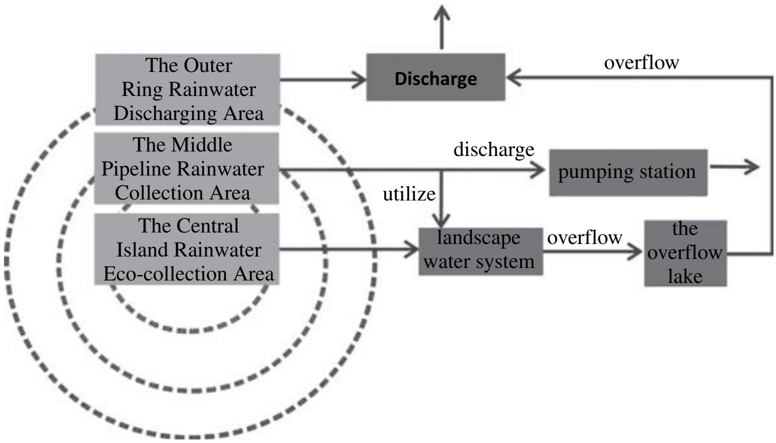

Fig. 17.2: Framework of Rainwater Recycling and Discharging System.

adopts several rainwater eco-collection practices, including grassed swale, permeable pavement and rain garden (Environmental Protection Agency (EPA), 2000) to build a rainwater utilisation demonstration area. Through these technologies, an integrated eco-system of rainwater collection has been built to infiltrate and store up rainwater, smooth out flood peaks, filter rainwater and mitigate surface runoff pollution. After water quality improvement through these facilities, this rainwater can directly supplement the landscape water.

Permeable Pavement

The road on the central island adopts permeable paving to collect rainwater. The central island is designed to accept minimal traffic with only one motor way. Vehicles are restricted from entering the central island and only foot traffic is permitted. Therefore, road surface pollution is significantly less than on the roads beyond the central area. The island's restricted road and sidewalks utilise permeable pavement with a coverage of 85.8%, enabling rainwater to permeate the landscape (Hijioka, Furumai, & Ichikawa, 2000). In this way, the permeable pavement can also reduce rainwater runoff.

In the concept of the green campus, and through such rainwater eco-collection technologies, the central island rainwater eco-collection area was built as a demonstration site for rainwater eco-collection. Due to the reduced traffic and the high use of permeable pavement, the runoff index was reduced to 0.4 from 0.9. Through this configuration, the central area significantly reduces rainwater runoff by 50% (Fig. 17.3).

The Rain Garden and Grass Swale

The green area of the central island was designed as a rain garden with different zoned areas. The rain garden, as a type of green space rainwater regulation


Fig. 17.3: Permeable Pavement on Campus.

technology, can make use of recessed areas to store up rainwater and dramatically prolong rainwater infiltration time, infiltrating and storing up the rainwater, smoothing out flood peaks and mitigating surface runoff pollution (EPA, 2000).

Typically, the elevation of the rain garden is higher than the elevation of the road. The drains are set within recessed green belts, whose elevation is lower than the road elevation but higher than the green space elevation. The rain garden can store rainwater runoff from the surrounding roads and buildings. Some rainwater infiltrates into the rain garden and some discharges into the drains. The rain garden is surrounded by the grassed swales, which can take in the overflow rainwater from the rain garden and further purify the rainwater.

The application of rain gardens like this can lower the risks associated with storm water, increase rainwater infiltration and underground water reserves and reduce the need to water green space. It can also reduce rainwater contamination to the river and lakes, reduce sedimentation and improve the soil (Asleson, Nestingen, Gulliver, Hozalski, & Nieber, 2010).

Research shows that rain gardens can reduce pollution in run-off rainwater through the adsorption, infiltration and degradation of plants and soil. Nitrogen, phosphorus and other organic pollutants can be reduced by more than 40–50% (Cheng, Yang, Huang, Xie, & Li, 2009) (Fig. 17.4).

Natural Erosion Control

The embankments of the campus water features planning rely on natural forms of erosion control (Arbex de Castro et al., 2011). Priority was given to aesthetics and recreational needs whilst maintaining ecological balance, landscape needs and engineering costs. Implemented controls include a mix of water plants and some artificial riverbanks giving diversity to the landscape and its aesthetics.

Fig. 17.4: The Rain Garden and Grass Swale on Campus.

The Rainwater Utilisation System at Middle Pipeline Rainwater Collection Area

The rainwater in this area is collected by the pipeline and is used to supplement landscape water within the campus. Surplus rainwater is injected into the Weijin River through pumping stations within and beyond the campus, which combines traditional rainwater collection methods and a low impact development rainwater utilisation concept. The middle pipeline rainwater collection area also adopts permeable pavement, especially in the parking zone.

Mass Balance Analysis of Available Rainwater Runoff and Landscape Water Supplement Demand

To calculate rainwater volume (Ministry of Housing and Urban-Rural Development of China, 2006), the following formula was employed: $W = 10\Psi_c h_y F$ (W represents total rainwater design runoff, m^3; Ψ_c represents rainfall runoff coefficient; h_y represent design rainfall intensity, mm; F represent catchment area, ha). The annual rainwater runoff on the campus was calculated to be 621,500 cubic metres. Accounting for various rainwater losses, such as evaporation, the actual annual rainwater runoff at campus is approximately 430,000 cubic metres before storm-water control measures were adopted. After employing these measures, the rainwater runoff was significantly reduced to an annual volume of 328,200 cubic metres. The assumptions and conditions applied to this calculation are as follows:

1. During the wet season from June to September, rainwater runoff from the rainwater collection areas is larger than the supply demand from the landscape waters. Surplus rainwater can flow into the overflow lakes through pipelines.
2. During the dry season in April, May and October, rainwater runoff from the rainwater collection areas is less than the supply demand from the landscape waters. Thus, rainwater during these three months needs to be collected.
3. The annual rainwater volume from the rainwater collection areas is larger than the water loss of the landscape waters (Fig. 17.5).

The Water Quality Conservation System of the Landscape Waters

Being open waters, the campus landscape waters can be impacted by many factors. It is hard to adopt a singular process or technology to deal with water contamination problems. The research informing this project tried to maintain long-term water quality in the landscape waters by controlling pollutants, increasing water self-purification capacity and water cycling. The integrated conservation measures of water quality are as follows (Fig. 17.6):

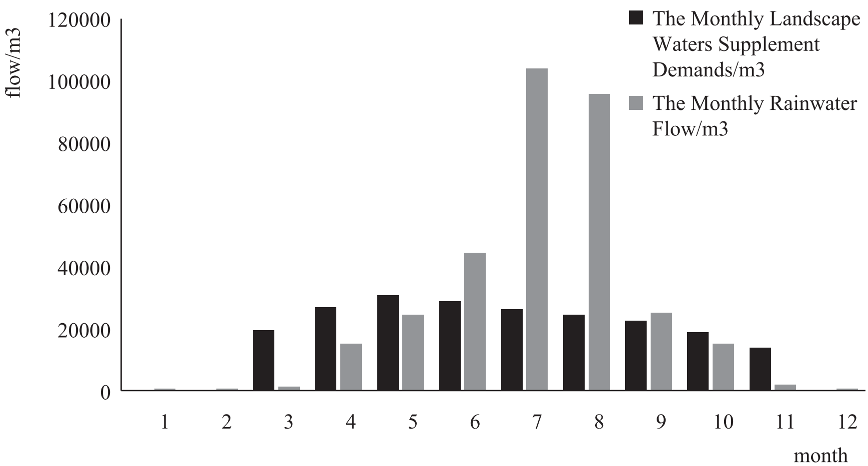

Fig.17.5: Monthly Rainwater Flow and Landscape Water Supplement Demands.

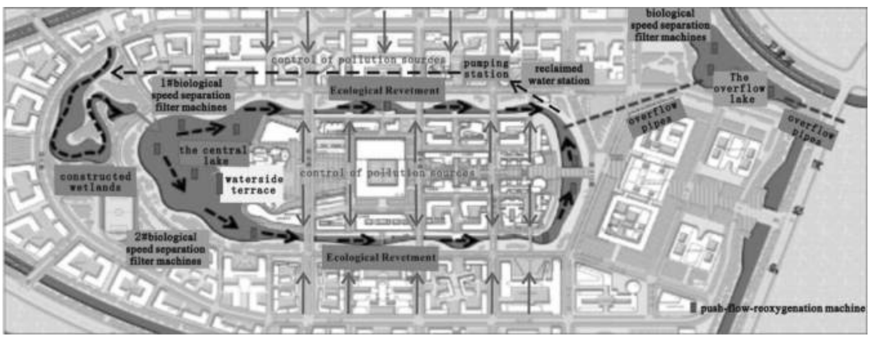

Fig. 17.6: Integrated Water Quality Conservation Measures for Landscape Water.

Pollutant Controlling Measures

Point source pollution control: a waste water treatment plant with a capacity of 1,000 m^3/day.

Non-point source pollution control: the rainwater eco-collection technologies at the central island.

Measures of Water Self-Purification Capacity Improvement

The Aquatic Ecosystem

The complete aquatic ecosystem consists of aquatic plants, aquatic animals living at different depths and microorganisms that attach to the plants and silt. The aquatic plants can oxygenate the water to improve water quality. The aquatic animals living at different depths can exert direct or indirect control on the plants and microorganisms under the water so as to lengthen the biological chain, making the water system more stable and diverse.

Artificial Enhanced Measures of Water Recycling

Push-Flow-Aeration Machines

The installation of a push-flow-aeration machine facilitates the cycling of landscape waters and injects oxygen into the water. There are 34 suites of push-flow-aeration machines set up at the central lake, the waterfront area and the overflow lakes. A total of 11 suites were installed at the overflow lakes. Based on the specific oxygen requirements determined by water quality and temperature, each aerator is set to operate for four to five hours a day.

Constructed Wetland

As a surface water treatment technology boasting environmental and ecological benefits, constructed wetlands achieve water quality improvement through the interaction of microorganisms, plants and other aquatic species and materials (Kadlec, 2008). The constructed wetland, lying to the west of the central lake, covers an area of 6,500 square metres. It consists of two parts, namely a 'reclaimed water filtration constructed wetland', and a 'sightseeing water cycle constructed wetland', covering three zones, A, B and C. The reclaimed water filtration constructed wetland is situated in Zone A, covering an area of 2,000 square metres. The water for this wetland comes from a reclaimed water station whose treatment capacity is 1,000 m^3/day (hydraulic loading of 0.5 $m^3/m^2 \cdot$day). This water, after the water quality treatment of the wetland, flows through the sightseeing constructed wetland into the central lake; the sightseeing water-cycle constructed wetland consists of Zones B and C, and covers a total area of 4,500 square metres. The water for this wetland comes from the cycled water of the central lake. The treatment capacity is 4,500 m^3/day (hydraulic loading of 1.0 $m^3/m^2 \cdot$day). Then the water flows through the sightseeing water cycle constructed wetland into the central lake.

Biological Filters

The central lake and the overflow lake are installed with two and one biological filters, respectively, as their artificial filtration measures. With totally immersed structures, every machine is cable of purifying 2,000 cubic metres of water every day.

Effect Analysis of the Integrated Measures

In accordance with the supervision data of the landscaped waters of the campus, the average concentration of COD and ammonia nitrogen are 44.49 and 1.23 mg/L, respectively. The COD concentration exceeds the limit of the threshold value (30 mg/L, surface water for sightseeing and recreation purpose) of the Chinese national surface water quality criteria GB3838-2002 (Ministry of Environmental Protection of China, 2002), while the ammonia nitrogen concentration is within the limit of the threshold value (1.5 mg/L).

In terms of the landscaped waters of the green campus, different artificial water quality improving measures have been taken to research water quality improvements and to meet the Chinese national surface water quality criteria. To further study water quality conditions after taking the integrated rainwater measures described here, including constructed wetlands, biological speed separation filter machines, and water circulation, a water quality model was established following the Water Quality Analysis Simulation Program (WASP) model (Ambrose, Wool, & Martin, 1993; Stow, Roessler, & Borsuk, 2003) used the US EPA. This allowed the simulation of changing conditions in water quality in accordance with the water quality data derived from the landscape waters of Tianjin University Campus and the rainwater quality supervision data taken in 2015. Taking the presence of COD and ammonia nitrogen as a water quality index, applying the WASP model revealed the following results (Fig. 17.7 and Fig. 17.8):

Comparing water quality conditions in 2015 to the water's current values, it can be concluded that the average concentration of COD and ammonia have been reduced to 34.87 and 0.92 mg/L, respectively. This equates to a COD and ammonia concentration drop of 21.62 and 25.2%, respectively. This downward trend in both COD and ammonia shows that the integrated control measures are making significant contributions to water quality improvement in the landscape waters. Through these measures, the water quality of the landscape waters is now meeting national surface water quality criteria.

Conclusion

Rainwater is a resource that should be easy to collect in university campuses because of their sizeable catchment areas and large impermeable footprints.

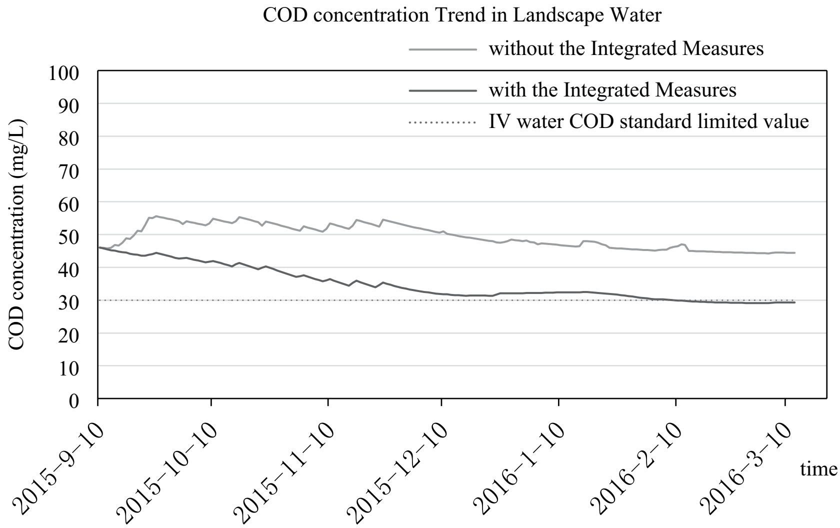

Fig. 17.7: COD Concentration Simulation in Landscape Water.

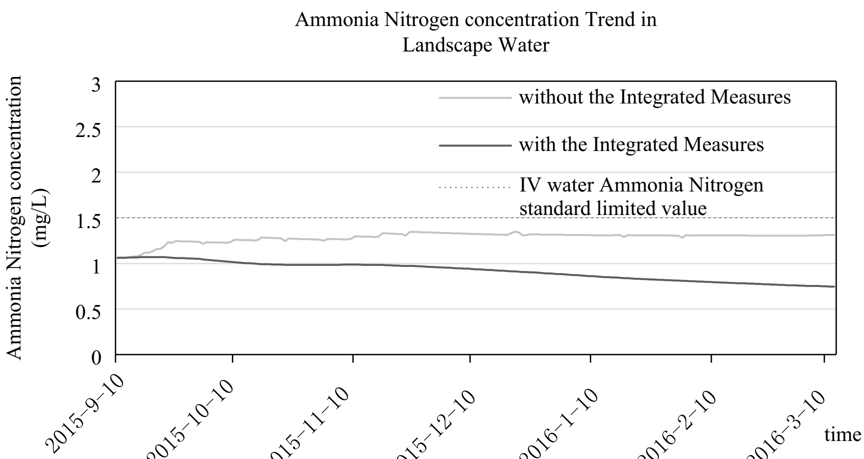

Fig. 17.8: Ammonia Nitrogen Concentration Simulation in Landscape Water.

If the rainwater can be utilised, it will not only cut down the cost of rainwater control, but also save water, relieving water shortage pressures. In the process of the construction of the water environment system in the new campus of Tianjin University, rainwater, as a major water supplement to landscape water, is effectively collected and used, which meets the technical guidelines for sponge city construction for urban areas, and reduces the cost of water replenishment. At the same time, a variety of low-impact development measures were adopted to control the influence of runoff pollution on water quality during rainwater utilisation. In the water circulation system, water quality conservation measures were adopted to improve water environment quality. The water quality of the campus landscape water in this way can meet the national surface water quality criteria.

This chapter introduced a sustainable rainwater utilisation and recycling model, based on the water environment construction, collection and utilisation of storm water, and landscape water conservation implemented at the new Tianjin University Campus. This integrated project should act as an exemplar in the planning of similar developments elsewhere in the future.

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Chapter 18

Re-Valuing Construction Materials and Components Through Design for Disassembly

Philip Crowther

Abstract

The expected operational lifespan of modern buildings has become disturbingly short as buildings are replaced for reasons of changing cultural expectations, style, serviceability, locational obsolescence and economic viability. The same buildings, however, are not always physically or structurally obsolete; the materials and components within them are very often still serviceable. While there is some recycling of selected construction materials, such as steel and concrete, this is almost always in the form of down cycling or reprocessing. One significant impediment to reuse is that buildings are not designed in a way that facilitates easy recovery of materials and components. This chapter explores the potential for the recovery of materials and components if buildings were designed for such future recovery, utilizing the strategy of design for disassembly. As well as assessing material waste, this chapter presents research into the analysis of the embodied energy in buildings, highlighting its significance in comparison with operational energy. Analysis at material, component and whole-of-building levels shows the potential benefits of strategically designing buildings for future disassembly to recover this embodied energy. Careful consideration at the early design stage can result in the deconstruction of significant portions of buildings and the recovery of their potential through higher order reuse and upcycling.

Keywords: Design; disassembly; reuse; architecture; construction; energy

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doi:10.1108/978-1-78714-619-820181024

Introduction

The construction industry is responsible for a significant portion of our material consumption and energy use. However, investment in the built environment is not always a long-term investment. In our industrialised societies, we are demolishing buildings after disturbingly short life spans. This demolition, largely driven by economic factors, accounts for a significant portion of our society's solid waste, which represents not only a waste of material but also creates significant negative environmental impacts. 'A simple and effective measure to reduce the environmental impact of construction is responsibe materials management at the construction stage' (Hammond & Jones, 2008, p. 96). If buildings were designed with their future deconstruction in mind we could re-value the materials and components in them, and also recapture the energy embodied within them. This embodied energy of the built environment has been estimated at between 15% and 20% of total energy consumption globally (Ramesh, Prakash, & Shukla, 2010). Within Australia it has been estimated at 10–20% of total energy consumption (Haynes, 2010). This chapter proposes the adoption of a design for disassembly strategy in the construction of the built environment in order to reduce the creation of solid waste, and reduce the amount of embodied energy entering landfills. It offers a number of simple design principles in order to achieve this, based on a critical analysis of case study buildings, construction systems and theoretical projects.

Waste in the Construction Industry

Quantities of Waste

Globally, the construction industry is responsible for a significant portion of material consumption, typically between 20% and 60%, and solid waste creation (Durmisevic & Yeang, 2009). In the USA, for example, the building and construction industry is responsible for approximately 60% of all material usage, with 30% of all solid waste produced coming from the construction and demolition industry (Guy & Ciarimboli, 2003, p. 2). The European construction industry accounts for approximately 50% of all materials taken from the natural environment, and accounts for approximately 40% of all solid waste created (Durmisevic & Yeang, 2009, p. 34). There is no comprehensive data for the whole of Australia; however, some recent research suggests that construction and demolition waste represents as much as 69% of all landfill (Li, Kuhlen, Yang, & Schultmann, 2013).

While some of this construction and demolition waste is recycled, the rates are low. In the USA, the rate of demolition material recycling is only 25–30% (Leigh & Patterson, 2006, p. 217). Recycling rates in Australia range by state from as low as 17% in Western Australia to 79% in South Australia, with a national average of 58% (Li et al., 2013). It is important, however, to note that the majority of this is low-level recycling, with little higher-order reuse. For example in the United Kingdom, only 13% of structural steel was reused, with a further 86%

being recycled, while in the USA, 97.5% of the structural steel recycled was not reused (Lee, Trcka, & Hensen, 2011). Perhaps the most significant issue in these high rates of waste and low rates of reuse is the short life expectancy of these materials, as the buildings they are part of are prematurely demolished.

Life Expectance of Buildings

Buildings are no longer demolished simply because they are old and structurally unstable. Buildings are now demolished for reasons of economic obsolescence, social obsolescence, locational obsolescence and in response to stylistic trends. Buildings that are designed to last 70–100 years are now being demolished after just 15 years, despite their perfectly serviceable physical presence (Durmisevic & Yeang, 2009, p. 134). In the USA, 27% of buildings that existed in the year 2000 are expected to be replaced by 2030 (Guy & Ciarimboli, 2003, p. 2). A study by the Athena Institute in the USA found that 30% of demolished buildings were less than 30 years old (Guy & Ciarimboli, 2003, p. 5).

While this life expectancy of modern buildings is disturbingly short, many parts of the buildings have an even shorter life expectancy, and in some ways, this is driving the overall life span down. For example, the envelope of the building, its outer skin, is typically only expected to last half or a quarter as long as the building structure itself, and the services and space fit-outs inside the building are expected to be replaced on an even shorter cycle. These different building layers have distinctly different life expectancies. We therefore need to consider the building at four separate and different levels or layers. The structure is the main supporting frame of the building, typically constructed of steel or reinforced concrete, or timber in smaller buildings. In domestic construction, the structure may be expected to be serviceable for 50–100 years (Adalberth, 1997; Fay, Treloar, & Iyer-Raniga, 2000), while in commercial buildings this is likely to be typically around 60 years (Storey, 1995), though there are of course many examples of structures lasting much longer.

The skin is the envelope of the building, the barrier between inside and outside that allows for control of the internal atmospheric conditions and resists the external weather; the outside walls, facade and roof. This skin has a shorter service life than the structure; typically, this is 25–50 years for domestic buildings (Fay et al., 2000), and 15–40 years for commercial buildings (Curwell, 1996). This shorter life expectancy is primarily due to physical deterioration, though it is often also simply a matter of stylistic refreshment (Crowther, 2009).

The services are the mechanical and electrical systems of the building, air conditioning plant, plumbing, data and electrics and vertical transportation. These systems are highly varied, and also can be the quickest to become outdated in their capacity and capabilities to deliver the level of service expected, as technology progresses and societal expectations increase. Services in domestic buildings usually last longer than in commercial buildings: 25 years (Fay et al., 2000), compared with 7–15 years (Storey, 1995).

The space is the internal partitioning and fixed furniture of the building: office partitions, internal dividing walls and fixed joinery. Spatial changes can occur on

Table 18.1: Life Expectancy of Different Building Layers, in Years.

Structure	Skin	Services	Space	Building Type
100	25–50	25	10	House: timber frame, brick cladding, ceramic tile roof (Fay, Treloar, & Iyer-Raniga, 2000)
100	25	10–20	4–10	Non-residential open building (Kendall, 1999)
30–300 (typically 60)	20	7–15	3–10	Undefined (Brand, 1994)
50	50	15	5–7	Office buildings (Duffy & Henney, 1989)
60–100	15–40	5–50	5–7	Office buildings (Curwell, 1996)
60 (assumed maximum life)	20	7–15	3–5	Commercial buildings (Storey, 1995)
65	65	10–40	5	Office buildings (Howard & Sutcliffe, 1995)
50 (assumed maximum life)	30–50	12–50	10	Freestanding singe unit dwelling (Adalberth, 1997)
40 (assumed maximum life)	36	33	12	Office buildings (McCoubrie & Treloar, 1996)
40	12–30	30–40	8–40	Timber frame, brick cladding (Tucker & Rahilly, 1990)

very quick cycles in commercial buildings as firms change their organisational structures, or simply refurbish their offices for aesthetic reasons; typically, these will last 3–5 years (Storey, 1995) compared with 10 years in domestic buildings (Fay et al., 2000).

Table 18.1 presents an overview of research into the various life expectancies of these layers of the building. Each of these different layers has its own different life expectancy, and this is resulting in unnecessarily high rates of material waste. Most buildings are still being designed as a single entity, as if they will last for centuries with little or no consideration for the potential end-of-life embodied within their different materials and components. As such, buildings are often demolished in line with the shortest life expectancy, even though parts are still serviceable.

Energy in the Built Environment

One significant aspect of these quantities of materials and waste in the built environment is the energy used to create these materials, construct our buildings and to operate them. ‘Worldwide, 30–40% of all primary energy is used for buildings and they are held responsible for 40–50% of greenhouse gas emissions’

(Ramesh et al., 2010, p. 1593). It has been a long-held view that the energy used to operate buildings (lighting, heating, air conditioning, etc.) is the only significant component of their full life cycle energy use; that the energy used to manufacture materials and components and assemble them into buildings (embodied energy) is very small in comparison. As such, most research into energy efficient buildings has focused on operational energy; however, it now seems that 'embodied energy consumption may be more significant than previously thought' (Troy, Holloway, Pullen, & Bunker, 2003, p. 9).

Operational Energy

The operational energy required for any given building is very dependent on the building type and what it is used for, and perhaps more importantly, where the building is located climatically. Worldwide data on the operational energy for office buildings shows a wide range of typical values, from as low as 290 MJ/a.m^2 to as high as 1,980 MJ/a.m^2 (Ramesh et al., 2010, p. 1598; Suzuki & Oka, 1998). For residential buildings, the values are typically as low as 540 MJ/a.m^2 to as high as 1,440 MJ/a.m^2 (Ramesh et al., 2010, p. 1598). It is important to note that these are typical values, and do not represent high-performance energy-efficient designs or buildings in extreme climatic locations.

The most significant factor in determining operational energy use is typically the climate. It is indeed because much research into building energy consumption has been conducted in the colder climates of northern America and northern Europe that operational energy has been so high, and traditionally been seen as the only significant component of life cycle energy use (Crowther, 2006).

Embodied Energy

The embodied energy of a material or product is the sum of all the energy required to produce that material or product. This will include the energy required for materials extraction, materials processing, transport and direct manufacturing. It also includes part of the energy required to create the buildings and machinery associated with all these steps in processing. Calculating embodied energy for construction materials and components is notoriously difficult and unreliable. Values vary considerably from one study to the next and vary considerably over time; older studies typically provide higher values than more recent research. Despite the variances 'they can be considered to provide good benchmarks for use in determining the life-cycle performance of buildings' (Hammond & Jones, 2008, p. 89).

For office buildings typical values for embodied energy are in the range of 7,000 MJ/m^2 to 17,000 MJ/m^2 (Ramesh et al., 2010). In one Australian study, the typical values were measured as being between 8,000 and 9,000 MJ/m^2 (Treloar, 1993). For residential buildings the typical values of embodied energy range from 4,000 MJ/m^2 (Hammond & Jones, 2008, p. 94) to as high as 14,100 MJ/m^2 (Fay et al., 2000, p. 38). We can also look at how this embodied energy is distributed between the different layers of the building (structure, skin, services and

Table 18.2: Typical Percentage of Embodied Energy in Different Building Layers.

Structure	Skin	Services	Space	Building Type
36	31	11	22	House: Timber frame, brick cladding, ceramic tile roof (Fay et al., 2000)
48	29	10	13	Single-storey office building (Yohanis & Norton, 2002)
33	29	24	14	Commercial building (Atkinson et al., 1996)
39	23	15	23	Single family dwelling (Haynes, 2010)
34	36	18	12	Multiple dwelling housing (Thormark, 2002)
32	28	26	14	Office building (Cole & Kernan, 1996)
36	34	–	19	Two storey office building (Oppenheim & Treloar, 1995)
30	–	15	25	Office buildings (Suzuki & Oka, 1998)

space fit-out), noting that those parts that typically have very short life spans constitute a considerable proportion of the overall embodied energy (see Table 18.2).

Total Energy

As previously noted, operational energy is clearly much greater than embodied energy and it has understandably received much greater research attention over the years. However, as buildings become more energy efficient in operation, the significance of embodied energy will proportionally increase. It has been shown previously that in a subtropical climate, operational energy is generally lower than in temperate regions of northern America and Europe so that embodied energy is proportionally greater and therefore of significance (Crowther, 2006).

Numerous studies in a range of international contexts have calculated that the embodied energy of a building, with a 50 year life expectance, is typically 5–20% of total life cycle energy (Ramesh et al., 2010). But as noted above, for low-energy use buildings, or energy-efficient buildings, embodied energy may actually be as much as 40–60% of total energy use (Thormark, 2007). A meta-analysis of the comparative energy use of 60 case studies calculated the embodied energy of conventional buildings between 2 and 38% of total life-cycle energy, and the embodied energy of energy-efficient buildings at between 9 and 46% of total life-cycle energy (Sartori & Hestnes, 2007). Other international studies have shown embodied energy to be as high as 67% of the total life cycle energy (Yohanis & Norton, 2002, p. 77).

Research in Australia has shown that embodied energy is typically equivalent to 10 years of operational energy for dwellings and 30 years of operational energy for office buildings (Sattary & Thorpe, 2012, p. 1402); this would equate to 10 and 33% of total life cycle energy for a building that lasted 100 years, or double those percentages for a 50 year life span.

Another study of 25 dwellings in Australia has shown a mean operational energy value of 810 MJ/a.m^2 and a mean embodied energy value of 9,900 MJ/m^2; showing that over a 50-year life cycle the embodied energy represents almost 25% of total energy (Pullen, 2000, p. 90). Yet another Australian study has shown embodied energy for residential buildings to be from 20% to 25% of the life cycle energy use (Troy et al., 2003). We can conclude that 'embodied energy is significant relative to operational energy' (Fay et al., 2000, p. 39).

It is worth noting that the direct energy of the actual building construction (operation of machinery and plan on site) is relatively small and has variously been measured at between 6 and 15% of the embodied energy or between 0.5 and 3% of the overall life cycle energy cost (Fay et al., 2000; Pullen, 2000, p. 88). Similarly the direct energy for demolition and removal of materials for disposal is very small and typically less than these construction percentages of total life cycle energy (Suzuki & Oka, 1998). The significance of this is that at such a small percentage, compared to the overall embodied energy, any additional construction energy required to implement a design for disassembly strategy will be far outweighed by the energy recovered from materials and components.

If we combine the life expectancies of different building layers from Table 18.1 and the typical embodied energy values from Table 18.2, we can see that with periodic refurbishment the embodied energy over 50 years is a significant portion of total life cycle energy (see Fig. 18.1).

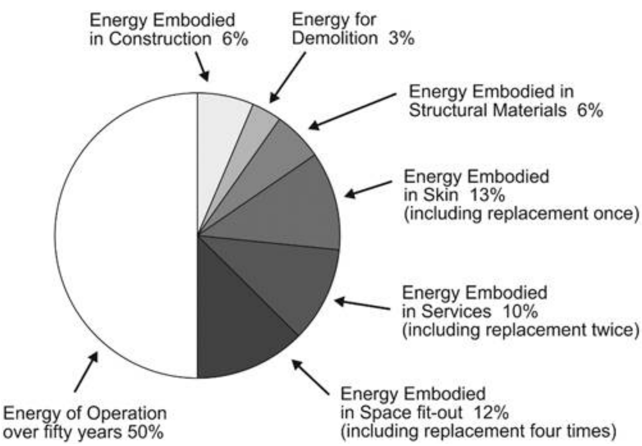

Fig. 18.1: Total Life Cycle Energy Use over the 50 Year Life of a Typical Office Building (author).

Recycling Energy

The reuse of building and construction materials for the same purpose as their original use can save up to 95% of the embodied energy since there is little or no processing involved. The recycling of materials, through reprocessing and remanufacture, is usually less efficient; typically saving from 5% for glass, up to 95% for aluminum, with most construction materials in the lower part of this range (Sattary & Thorpe, 2012). One study of actual building demolition waste showed a potential embodied energy recovery through recycling of 37–42% (Thormark, 2002).

The ability to reuse materials and components is much more energy wise than recycling. Despite this, the majority of materials that are salvaged are recycled or down-cycled, not reused. For example, as noted earlier, rates of steel recycling in the UK and the USA are 86% and 97%, respectively, but with little or no direct reuse (Lee et al., 2011, pp. 68–69). Similarly large amounts of reinforced concrete are down-cycled into aggregate used for road base and the like.

One study of life cycle energy use shows that the periodic refurbishment and maintenance of a building, over a 50-year period, can be more than the initial embodied energy (Yohanis & Norton, 2002). If the materials and components removed during refurbishment are sent to landfill then the embodied energy being lost can be more than the initial embodied energy of the building. The potential for recovering the embodied energy through recycling and reuse is thus significant. Strategies are needed to facilitate higher-order recycling such as the reuse of components or even whole building relocation (Fig. 18.2).

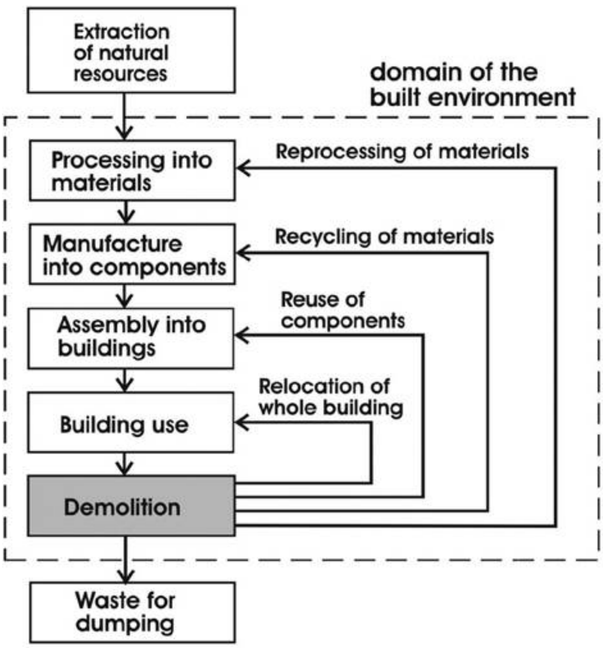

Fig. 18.2: Levels of Reuse and Recycling (Author).

Design for Disassembly

It has been shown that a significant hindrance to higher rates of materials and component reuse is the inability to easily and economically disassemble them from each other (Crowther, 2009). This is especially true at the junction of the layers, between structure, skin, services and space fit-out. The future capacity for reuse and recycling is being determined at the initial building design stage. If buildings were designed to facilitate future disassembly then higher rates of high-order reuse and embodied energy recovery could be achieved.

Historically, there have been many such buildings designed with future deconstruction in mind, and although they generally do not represent standard practice in the construction industry, they do provide a valuable insight into the possibilities of recovering and reusing materials and their embodied energy. Since humans first started to leave the shelter of caves as nomads their structures were made for reuse; for example, tents were designed for quick assembly and disassembly, with readily separated structure and skin. In the Middle Ages, both in Western and in Eastern architectural traditions, there is a history of timber-framed construction where structural members were joined in ways that permitted future disassembly for reuse and reconfiguration. Internal partitioning systems were modified as users (families) changed over time. The later development of such construction systems enabled colonial occupation of much of the globe in the eighteenth and nineteenth centuries, through the use of pre-fabricated buildings shipped around the world and assembled and disassembled as European settlements came and went (Peters, 1996).

Technological developments in iron and steel facilitated further experiments in temporary buildings that were assembled and disassembled from a kit of parts. These ranged from small portable cottages of corrugated sheet iron to the 'Crystal Palace' of 1851, when Britain hosted the Great Exhibition of the Works of Industry of All Nations. This 560 m long building of cast iron and standardised panels of glass was specifically deigned to be temporary and was later relocated and reconfigured on a different site (Strike, 1991). More recent World Expositions have also fostered experiments in buildings designed for disassembly, such as the Capsule House and Takara Pavilion of Expo '70 in Osaka, Japan.

In the 1960s, John Habraken (1972) introduced the notion of open building systems through his research and publications; a system that recognised the different time-related layers of the building. While Habraken's work was initially concerned with mass housing, the principles of open building have achieved widespread interest, both theoretically and practically. There are now many buildings, including commercial office buildings and shopping centres that utilise an open building system that recognises the different layers of the building (Kendall, 1999).

Most recently the Olympic Stadium in London was designed so that the upper tiers of seating and the upper roof could be disassembled from the lower sections of the stadium after the Olympic Games, and relocated for reuse on a different site (Olympic Stadium Populous Architects, 2012). On a smaller scale in the city of Christchurch, New Zealand, the Re:START mall is a retail precinct

Fig. 18.3: Re:START Shopping Mall, Christchurch, New Zealand (Photo By Author).

constructed from shipping containers and other demountable components. This temporary response to the 2011 earthquake, which destroyed most of the buildings in the central business district, provided new retail facilities on a vacated city site using modified shipping containers and standardised glazing panels. This outdoor shopping mall has already been disassembled and relocated once, as the construction of permanent buildings is commenced and completed (Fig. 18.3).

Analysis

A review of these case studies and many others has revealed a number of recurring principles for design for disassembly (Crowther, 2009, pp. 231–235). The review was guided by a soft systems methodology (Checkland & Scholes, 1999) in which heuristic principles are developed in response to real-world problems. Over 75 buildings or construction systems were assessed using a method of critical reflection (Mezirow, 1990) to make new interpretations of existing knowledge in order to establish deeper understandings; in this case an understanding of how to address the mismatch between issues of environmental responsibility (particularly the recovery of embodied energy) and current practice in the construction industry. Recurring technological themes were identified and developed into a number of heuristic principles, including:

- Minimise the number of types of materials.
- Minimise the number of types of components.

- Avoid secondary finishes to materials.
- Avoid toxic and hazardous materials.
- Use mechanical connectors not chemical.
- Use modular design.
- Provide adequate access to components.
- Allow for (dis)assembly using common tools.
- Size the components to suit means of handling.
- Apply realistic tolerances during manufacture.
- Limit the number of types of connectors.
- Allow for parallel (dis)assembly between layers.
- Use lightweight materials and components.
- Identify points of disassembly.
- Sustain information about components and systems.

Discussion

These principles are neither complex nor surprising. What is surprising though is how little regard there is in the construction industry for considering these principles as a way to reduce the environmental burden and reduce the material waste in our built environment. The case study buildings and systems are neither extraordinary nor overly sophisticated; they are however well-designed buildings in response to a clear intent to allow for adaptation in the future.

If buildings were designed for disassembly the potential for embodied energy recovery could be in the order of 25–50% of total life cycle energy. Following a strategy of design for disassembly may require additional material and energy input at the initial stages, though as shown, the energy for actual on-site construction is comparatively small. By comparison the potential material and energy recovery is significant. It is also worth noting that such energy and material recovery would come with significant financial savings. Material costs, as a percentage of building costs, vary widely depending on material choice and construction method. It is however reasonable to expect that materials may typically be half of the overall build cost; as such, any material and component reuse will represent significant financial, energy and material savings.

Conclusion

The recycling and reuse of construction materials and components can significantly reduce the environmental burden of material waste and energy consumption. While there are many examples of buildings that have facilitated future deconstruction, design for disassembly is not an accepted part of mainstream construction practice. This chapter has proposed the adoption of a design for disassembly strategy in the construction industry in order to reduce material and energy consumption through increased rates of recycling and reuse, and also to reduce the quantity of waste created by the untimely and premature demolition of our buildings. Critical analysis of over 75 case study buildings and construction systems has resulted in the development of a number of simple design principles.

The implementation of these principles has the potential to increase levels of future disassembly in our buildings, facilitating higher rates of component and material reuse, and energy recovery, while reducing solid waste.

The reuse potential of a material or component is only as good as the initial design is in allowing future recovery and reuse. The investment in our built environment can offer returns through the re-valuing of materials and components, if we are wise enough to consider their reuse potential at the design stage and allow for future disassembly.

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Chapter 19

Construction and the Circular Economy: Smart and Industrialised Prefabrication

Abbas Elmualim, Sherif Mostafa, Nicholas Chileshe and Raufdeen Rameezdeen

Abstract

This chapter discusses the profound and influential impact the construction industry has on the national economy, together with the huge negative effect it has on the environment. It argues that by adopting smart and industrialised prefabrication (SAIP), the Australian construction industry, and the construction industry globally, is well positioned to leverage the circular economy to advance future industries with less impact on our natural environment. It discusses aspects of the application of digital technologies, specifically building information modelling, virtualisation, augmented and virtual reality and 3D printing, coupled with reverse logistics as a proponent for advancing the circular economy through smart, digitally enabled, industrialised prefabrication. It further postulates a framework for SAIP for the circular economy.

Keywords: Circular economy; construction; prefabrication; smart and industrialised prefabrication; building information modelling; Reverse logistics

Introduction

The construction industry output contributed almost 10% to Australia's GDP in 2014–2015 (ABS, 2016). However, the industry has been criticised for the huge impact it has on the environment, especially due to the large amounts of construction waste it generates. There is an urgent need globally as well as nationally to advance sustainable construction in order to progress the circular economy. It is vital for Australian construction to adopt industrialised and smart prefabrication to address the sustainability agenda. Various feasibility studies worldwide

Unmaking Waste in Production and Consumption: Towards the Circular Economy, 323–336

doi:10.1108/978-1-78714-619-820181025

have shown that the application of prefabrication is the way forward in improving the performance of the construction industry (Goulding, Arif, Pour-Rahimian, & Sharp, 2013; Mostafa, Chileshe, & Abdelhamid, 2016; Veld 2015; Zhai, Reed, & Mills, 2014). Prefabrication has been proven to reduce construction waste and improve the environmental performance of construction processes. By harnessing knowledge in back-casting and reverse logistics (RL), advocating mutual collaboration and utilizing rapidly developing digital technologies such as building information modelling (BIM), the construction industry, in Australia and worldwide, is well positioned to contribute to and benefit from the circular economy (Chileshe, Rameezdeen, & Hosseini, 2016; Elmualim & Gilder 2014; Mostafa et al., 2016).

Against this background, this chapter is aimed at exploring the synergies between the concepts and principles of RLs, smart (digital) technologies and industrialised prefabrication in advancing the circular economy. The evidence is provided of how the identified concepts and principles can be utilised in ensuring that by-products from the construction project life cycle can be retained and used as input for other activities. Secondly, the chapter further demonstrates how the linkages between closing the loop of the construction supply chain (CLSC) through embracing RL, and some components of the circular economy such as reuse and recycle, and design and manufacture for deconstruction (DMfD) can be implemented at the meso- and macro-levels. Thirdly, some of the critical drivers for this, such as a knowledge-sharing environment and open culture, as a basis for mutual collaboration, are further highlighted. Finally, the chapter concludes by discussing the crucial role played by stakeholders such as designers, builders, suppliers, demolition subcontractors, salvaging companies and consumers, in bridging forward and RLs to stimulate the circular economy.

Background to the Australian Construction Industry

Construction has always been one of the most important industries in any economy, through its provision of many levels of employment and the value of work it can add to the gross domestic product (GDP). The Australian construction industry is the fourth largest contributor to the country's economy, and accounted for 9.5% of the Australian GDP in the financial year 2014–2015 (Reserve Bank Australia, 2016). In the UK, the construction industry contributes to 8% of the country's GDP, with over 201,100 enterprises, and an annual turnover of £152bn, and approximately 1.4 million employees (Goulding, Pour-Rahimian, Arif, & Sharp, 2012). The construction industry comprises both private and public enterprises engaged in three broad activities/sectors, namely residential building, non-residential building and engineering construction. The GDP breakdown of these construction sectors is broadly proportional in different countries. For example, the Australian residential sector contributes significantly to the national economy, with the overall production value reported as AUD$16 billion in 2015–2016 (ABS, 2016). This sector involves many building organisations constructing semi-detached houses, townhouses, flats, units and apartments (Dowling, 2005).

However, given the economic importance of the construction industry, it is considered to be one of the least environmentally sustainable industries in the world. The construction industry contributes to 23% of air pollution, 50% of climatic change, 40% of drinking water pollution and 50% of landfill waste (Willmott Dixon Group, 2010). The US Green Building Council (USGBC) reported that the construction industry accounts for 40% of worldwide energy usage, with estimations that by 2030, emissions from commercial buildings will grow by 1.8% (USGBC, 2016). To reduce material consumption and preserve natural resources, the concept of sustainable construction and green development must be considered across the entire construction supply chain, including procurement, planning and design, construction techniques and building materials. The circular economy has profound implications in the construction industry, as it encourages consideration of sustainability in terms of reducing the use of natural resources. It promotes closed-loop, value-recovering manufacturing and construction methods that operate to ensure environmental protection as well as financial sustainability (Ellen MacArthur Foundation, 2013). This chapter presents three concepts that are aligned with the circular economy's principles: digital technologies, RLs and prefabrication. These concepts have the capacity to foster a greater balance between the built environment and natural environment.

Construction in the Circular Economy

With the pressures posed by climate change, it is argued that the widely adopted economic model of make, use and dispose of waste is no longer viable. The time is right to take advantage of the circular economy, as advocated by Stahel (2010). 'The circular economy is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and renewable flows' (Ellen MacArthur Foundation (2016, p. 18). The concept of the circular economy is underpinned by three principles: preserve and enhance natural capital, optimise resource yields by circulating products, components and materials, and foster system effectiveness by revealing and designing out negative externalities. The adoption of the circular economy will address finite resource challenges for business and economies, and should generate growth, create jobs and reduce environmental impacts (Ellen MacArthur Foundation, 2015). The concept is being adopted by the UK, the European Union (EU) and China. It is forecasted that the circular economy will contribute US$1 trillion per annum globally by 2025 (Voulvoulis, 2015). Geng and Doberstein (2008) suggested that China can achieve a leapfrog development based on the circular economy.

The EU has recently developed an action plan for transitioning into the circular economy as an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. The EU (2015) has demonstrated its commitment to eco-design and the development of strategic approaches to chemicals, and targeted action in areas such as plastics, food waste, construction, critical raw materials, industrial and mining waste, consumption and public procurement. The EU further stipulates construction and demolition as amongst the largest contributors to waste. This emphasises the importance of the circular economy, and the move away from the cradle to the grave towards cradle to cradle approaches, as advocated by McDonough and Braungart (2002). Better sustainable and ecological design will render products more durable and easy to use, repair, upgrade and remanufacture. It is argued that the construction industry is well positioned to benefit from the circular economy, reducing its present environmental impact and creating future economic opportunities. Smart and industrialised prefabrication (SAIP) provides an opportunity to further advance the transition into the circular economy in the construction sector. By focusing on users' needs rather than products only (Tukker, 2015), the industry can provide high-performing projects, products and services that can stimulate the economy, and meet the needs of clients and the broader society with significantly less impact on the environment.

BIM and Digital Technologies in Construction

Information and Communications Technology, and digital technologies in general, are shaping modern society. These have been widely embraced by individuals and organisations alike. Enabled by the unprecedented rapid development in computing power, connectivity, mobility and data storage capacity over the last few decades, digital technologies provide opportunities to achieve higher productivity (Productivity Commission, 2016). The construction industry is slowly embracing digital technologies and especially BIM to reap the benefits they provide in the successful delivery of construction projects (Elmualim & Gilder, 2014).

BIM, as a tool, is the process of generating and managing building data during its life cycle (Kymmell, 2008). It uses three-dimensional and real-time dynamic building modelling software to increase productivity in building design and construction (Eastman, Teicholz, Sacks, & Liston, 2008; Holness, 2008; Kymmell, 2008; Sacks et al., 2010), and for facilities management (Asojo & Pober, 2009; Elmualim & Gilder, 2014). It can be described as a virtual design and construction that enables collaboration amongst the construction project team (Harvey, Bhgat, Gerber, Kotronis, & Pysh, 2009). It has been widely used to represent the entire building life cycle, including the processes of construction and facility operation. Bills of quantities and shared properties of building materials, components and assemblies can be extracted readily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities (Kymmell, 2008; Sinopoli, 2010). Furthermore, BIM provides a common platform for collaboration by sharing both graphical and non-graphical information of any building or infrastructure project. This is seen as one of the greatest strengths and benefits of the adoption of BIM, particularly its integration of the design team (Elmualim & Gilder, 2014).

BIM allows the interoperability requirements of construction documents, including drawings, procurement details, environmental conditions, submittal processes and other specifications for building quality. It is argued that BIM can be utilised to bridge the information loss associated with handing a project from the design team, to the construction team and to the building's owner/operator, by allowing each group to add to and reference back to all information they acquire during their period of contribution to the BIM model (Kymmell, 2008). Therefore, BIM can save time and reduce costs by reducing construction change orders (Sinopoli, 2010).

It is envisaged that the application of BIM, virtualisation and 3D printing as a tool for SAIP, is vital to its advance within the construction industry. There is little doubt that object-based parametric modelling has had an enormous influence on the emergence of BIM. These are essential in representing and documenting prefabrication components and assemblies. There are many design, analysis, checking, display and reporting tools that can contribute to the BIM of a building, such as Revit, Bentley Systems, ArchiCAD, Digital Project, Architectural Desktop (AutoCAD-based applications), Tekla Structures and DProfiler. Many information components and information types are needed to fully design, develop and construct a prefabricated building (Eastman et al., 2008). The BIM tools considered here are only the latest in several generations of tools, but they are also proving to be revolutionary in their influence (Eastman et al., 2008). Object-based parametric modelling resolves many of the fundamental issues in architecture and construction (Kymmell, 2008). Eastman et al. (2008) have reported a reduction in drawing errors due to BIM providing access to a central building model, the elimination of repetitive designing and drawing, the elimination of errors due to spatial interferences and design ambiguities and a central database of data, to be some of BIM's immediate payoffs. There are various challenges in adopting BIM, however, such as resistance to change, adaptation of existing workflows to lean-oriented programmes, training, clear understanding of responsibilities amongst the construction team and a lack of understanding of the required high-end hardware resources (Arayici et al., 2011).

However, the technology is fast advancing and further integrated into gaming for real-time visualisation (Yan, Culp, & Graf, 2011), for assessing economic impacts (Jung & Joo, 2011) and for addressing conflicts and safety problems (Zhang & Hu, 2011). With the widening debate on sustainability, BIM systems are increasingly utilised for sustainable design processes and design rating analysis (Azhar, Carlton, Olsen, & Ahmed, 2011). It is argued that the time is right for the construction industry to adopt BIM, virtualisation, virtual and augmented reality and 3D printing as tools for SAIP. These technologies can be used to enable the exploitation of mobile devices, such as mobile phones and tablets, as well as cloud-based applications and the Internet of Things. This will enable the industry to meet clients' requirements, delivering projects on budget and on time, as well as meeting societal needs as a whole.

Prefabrication in Construction

The industrialisation of construction adopts the idea of thinking of construction as a production process, and simplifies and reduces on-site construction activities. Most on-site activities are assembling and testing while fabrication is conducted offsite. Industrialisation simplifies the site-based processes and uses the benefits of repetition (Koskela, 1992). On the other hand, the entire construction process gradually becomes more complicated due to the increased need to coordinate between the two working locations (offsite factory and construction site) (Koskela, 2003). Three main principles contribute to the development of the industrialisation of construction: standardisation, prefabrication and systems building (Gann, 1996).

Prefabrication of construction encompasses both standard products and components as well as building systems, as explained in Björnfot and Stehn (2004). Prefabrication is the general term used for the fabrication of building components at the offsite facility, as well as their subsequent assembly on the construction site (Mostafa et al., 2016). Interchangeable terms and definitions based on the method of construction and project development processes are employed in different countries. Prefabrication is termed as industrialised building systems in Malaysia and China (Zhai et al., 2014), and offsite production (OSP) or offsite manufacturing (OSM) in the UK and Australia (Blisams & Wakefield, 2009; Pan & Goodier, 2012). Gibb (1999) stated that OSP is the term used by the UK government to describe innovation in housebuilding, and the transfer of work from the construction site to a factory.

Prefabrication is classified based on the type of product produced and the location of the production (Nadim & Goulding, 2011). Pasquire and Gibb (2002) categorised prefabrication into four types: component subassembly, non-volumetric pre-assembly (panel building systems), volumetric pre-assembly and modular assembly, hybrid (semi-volumetric) and a sub-assembly component. The four types of prefabrication have been employed in buildings and civil engineering works, and have been used successfully for the construction of houses, hospitals, hotels and civil engineering projects (Ngowi, Pienaar, Talukhaba, & Mbachu, 2005).

In the UK, prefabrication or OSP is adopted in constructing public housing, offices, retail, universities, hotels and supermarkets (Goodier & Gibb, 2007). Blismas (2007) stated that prefabrication is centred on commercial, and semi-detached and regional residential buildings. The adoption of prefabrication in the construction of buildings and civil engineering works is due to its benefits compared to conventional construction methods (Pan, Gibb, & Dainty, 2007). According to Blismas & Wakefield (2009), benefits of OSM include a reduction in construction time and of health and safety risks, and increased quality and productivity. In addition, the uptake of prefabrication contributes to a higher level of environmental sustainability, including a reduction of waste and carbon emissions (CRC LCL, 2014; Zhai et al., 2014).

Reverse Logistics in Construction

RL is an important segment of the circular economy, where the reverse flow of resources is effectively managed, reusing, re-manufacturing or recycling resources to regain the product's value. The RL process starts with the deconstruction of a building. Then the salvaged products are acquired, tested and graded for their quality. The re-processing and re-distribution of these products to the point of consumption will take place at the end. Fig. 19.1 shows the RL process as it relates to the construction industry.

Past research suggests that economic factors drive RL more than other factors. Issues related to deconstruction, inability to assure the quality of reclaimed resources, along with a lack of information sharing among stakeholders, were found to be the major barriers to the adoption of RL. Research suggests deconstruction is the weakest link in the RL process, which results in deficiencies of quality and consumer dissatisfaction with the recovered product. Deconstruction is defined as 'the systematic disassembly of buildings to enable the reuse and recycling of construction materials' (Leigh & Patterson, 2006, p. 217). As the starting point of the reverse flow of resources, deconstruction is a prerequisite for efficient and cost-effective 'Closing the CLSC' (Kibert, 2012). Disassembling a building not designed for deconstruction also leads to sub-optimal recovery and reuse of products (Saghafi & Teshnizi, 2011). The feasibility of implementing CLSC in construction mainly depends on the ability to undertake deconstruction at the beginning of the reverse supply chain. Therefore, according to Kibert (2012), one of the key challenges of adopting CLSC in construction is to implement Design for Deconstruction (DfD) and the selection of materials, products and assembly methods that enables deconstruction at the end-of-life of a building.

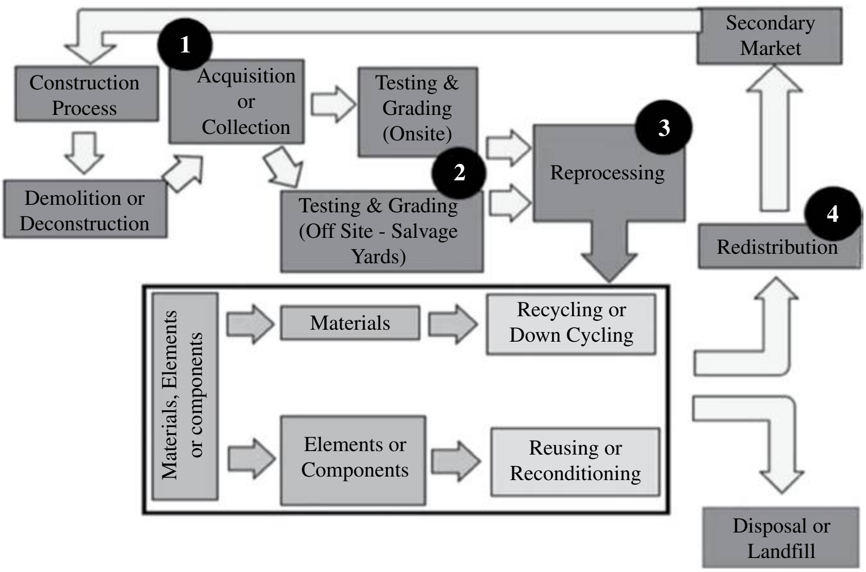

Fig. 19.1: Reverse Logistics Process in Construction. *Source*: Adapted from Hosseini et al. (2015), Schultmann and Sunke (2007), Nunes, Mahler, and Valle (2009)

Lack of information sharing among stakeholders within the RL process is another factor that hinders widespread adoption of CLSC in the construction industry (Hosseini et al. 2015). It also results in fragmented markets for recovered products. Uncertainties about recovered products and their quality, testing and grading outcomes, suitability for structural applications, along with their cost compared to virgin products, are some of the major issues that customers face at the market end of the supply chain. Due to these uncertainties, the adoption of RL is presently limited to very few materials such as recycled aggregate concrete (RAC). In reality, only a tiny percentage of resources is efficiently reclaimed in the construction supply chain, suggesting the sector is far behind others in moving towards a circular economy. However, the construction industry is a major consumer of materials and at the same time a major producer of waste. Huge amounts of materials and energy are embodied in the built environment, and at the end-of-service-life they are typically disposed in landfills. RL has the potential to bring these lost resources and embodied energy back into the building life cycle, thus promoting the circular economy.

SAIP brings an enormous opportunity to remedy the above shortcomings by incorporating DfD at the inception of a project, and the use of that information by the builder, facilities manager, demolition sub-contractor and salvaging company, during the entire life cycle of the building. However, at present, conventional design and construction techniques are not capable of supporting the circular economy, as these are limited to forward logistics operations. If implemented, SAIP can convey the quality of embodied resources in a building, to the testing and grading stages of the RL process, and help salvaging companies improve the quality of the products salvaged during re-processing. However, conventional design and construction operations are not capable of capturing that information to help plan recovery, testing, grading and re-processing. These information flows are crucial in promoting recovered products among customers, including architects, engineers and the clients of new buildings. Digital technologies coupled with industrialised prefabrication are gaining popularity as they contain all the necessary ingredients for a circular economy to thrive.

Creating Synergy through Saip

The circular economy involves changing the very basis of how we build, as we know it, to recover materials from end-of-service-life of a building and reuse it in new developments. It is similar to natural mechanisms where the loop of the flow of materials is closed – in a CLSC. RL is the medium through which CSLC is implemented, which essentially enables the recovery and transferring of the resources back to the built environment. According to Tibben-Lembke and Rogers (2002), RL is best defined as follows:

> The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of creating or recapturing value, or proper disposal. (p. 271)

In simple terms, it is the movement of resources in the opposite direction to that typically found in new constructions, for the purpose of creating or recapturing value. As shown in Fig. 19.2, SAIP facilitates the reuse of an entire facility on the same premises by adaptive reuse or by reconstructing it in a different location with minimal environmental consequences. It also allows the recycling of parts and components through off-site processes to recapture value in terms of the tangible products as well as the information flow associated with these. The SAIP model preserves and enhances natural capital while enabling the optimisation of resource yield by circulating products, components and materials across their life cycles.

SAIP captures all information about construction material and products, from their mining, part or component manufacture, assembly and product manufacture, construction, to the in-use and facilities management phase. In-use information flows back into the SAIP database to inform the design and manufacture of old and new products. The SAIP database for all products and assemblies can further help construction practitioners and users to assess design and construction options, as well as the opportunity for the 3D printing of construction parts and components (Figs. 19.2 and 19.3).

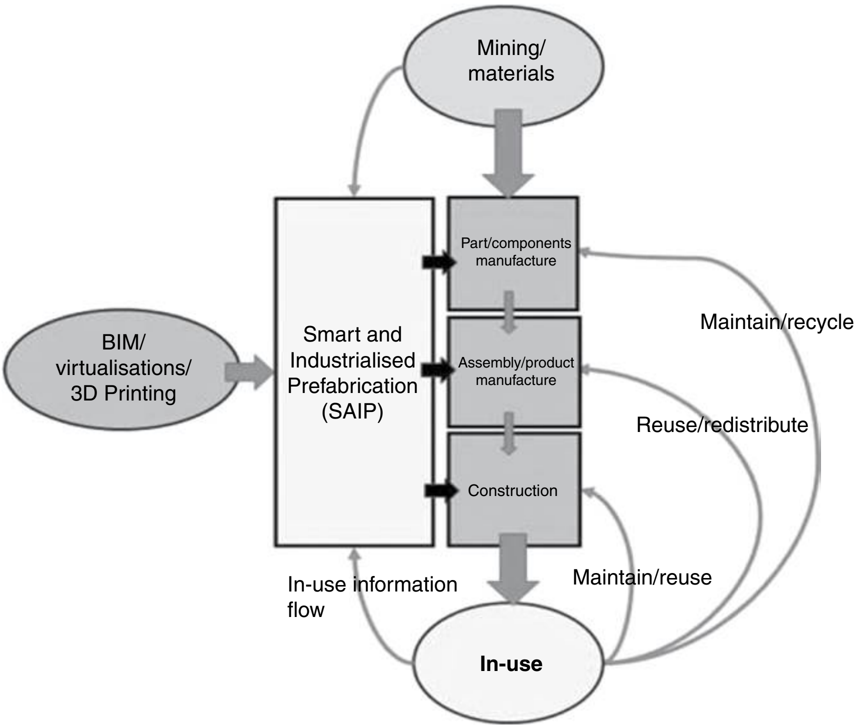

Fig. 19.2: Framework for Circular Economy. *Source*: Adapted from Ellen MacArthur Foundation (2015).

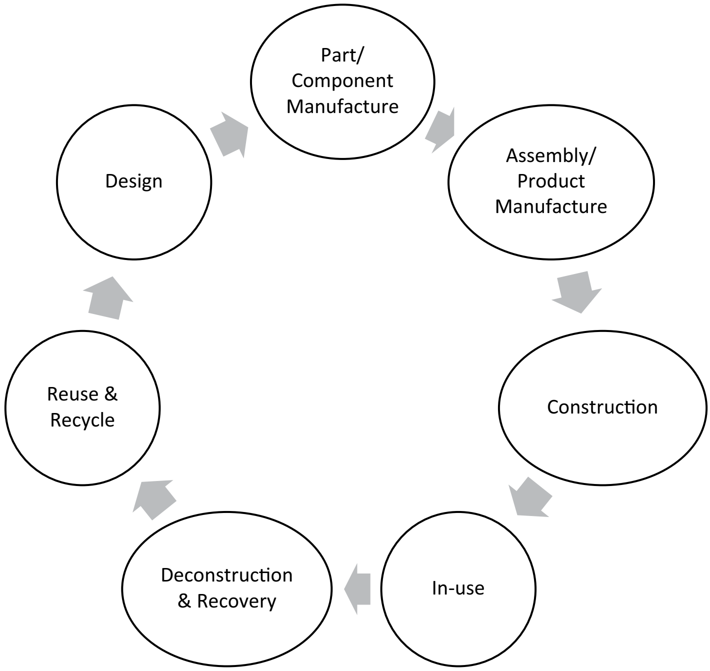

Fig. 19.3: Smart and Industrialised Prefabrication Model.
Source: Adapted from Ellen MacArthur Foundation (2013).

During the design stage of SAIP, digital technologies such as BIM and virtualisation enhances DMfD capabilities in addition to supporting designing out negative externalities, in this way creating the foundations of the circular economy. Compared to conventional design, SAIP encourages collaboration among stakeholders from the very beginning. The part/component manufacture stage greatly improves the quality of output through off-site processing while reducing wastage. Off-site manufacturing provides the guarantee for effective deconstruction at the end-of-service-life of these facilities, which is a prerequisite of the circular economy.

Assembly/product manufacture is an important stage of the SAIP process, where very high-quality products will ensure productivity gains during on-site construction. Simplified and reduced on-site construction also ensures shorter project durations and fewer workplace health and safety risks. During usage, these facilities will enjoy enhanced maintenance through BIM-enabled data and sharing of information, in design as well as in-use. Facilities managers will be encouraged to update the models with real-time data that would help plan and execute well informed testing and grading operations, resulting in high-quality re-processing of salvaged products at the end-of-service-life. SAIP using BIM is expected to help the circular economy by linking testing, grading and re-processing stages of RL operation, to information flows from design through construction and facilities management stages of a built asset. In addition, BIM can convey the test and grading outcomes to the re-processing as well as marketing stages of parts/components of a facility, enhancing confidence among stakeholders including customers at the end of the supply chain. BIM-enabled information is also invaluable as it can involve the reuse of modular systems, or their re-assembly, including adaptive reuse. 3D printing can further be utilised in the production of some of these parts and components. In summary, Fig. 19.3 shows a graphical representation of the synergy between smart, digitally enabled prefabrication and the circular economy in construction.

Conclusion

The circular economy as a concept is evolving to reverse the present detrimental 'linear' direction of design, production, consumption and waste. It enables new through-life cycle design and adopts a cradle-to-cradle approach, hence eliminating waste, conserving resources and stimulating new economic activities. The Australian Construction Industry, and the wider, global construction industry, is well positioned to leverage the potential of the circular economy by adopting SAIP. Various digital technologies including BIM, virtualisation and 3D printing are changing the way we design, build and operate assets. These technologies together with the adoption of concepts such as construction RL and open collaboration in prefabrication are seen as enablers to advance the construction industry into a more innovative and agile industry, and a more sustainable one.

This will result in better project delivery, on time and on budget, that meets the clients' requirements as well as societal needs, with a greatly reduced impact on the natural environment. A model for SAIP that exploits the application of digital technologies in prefabrication can be developed to advance the circular economy for the wider benefit of the construction industry and society at large. Future research work must include the development and testing of a prototype for the SAIP model and its utility in practice. The implication of adopting such a model and its impact on construction stakeholders' engagement in collaborative practices also warrants further research.

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Afterword

Vaughan Levitzke, PSM

This book is not the first, nor will it be the last word on the 'Circular Economy'. What it does is to bring together leading researchers that have collaborated to look at the concept from a number of perspectives and disciplines. This whole realm, however, very much remains a work in progress, and presents fertile ground for much more work to be done.

A circular economy model encompasses all of the previous sustainability thinking of the past, but places this squarely in an economic context. It's so obvious, I don't know why this wasn't done much earlier in our history. Linear models are out, circular is in, but we aren't yet applying the principles. Waste, I'm reminded, is a global growth industry, and there's no end (yet) in sight.

One thing is for sure, a circular economy requires both a multidisciplinary approach and a collaborative mind set. This book shows the intersections of some of these disciplines, however, many more are yet to be fully engaged on the concept. The book draws on experiences and thought from across the globe, including China, a country that has grasped the idea for a long time, and is now trying to desperately implement a more circular economy so as to improve the well-being of its citizens and its environment (Chapter 3). China is not alone, most of Europe and India also know that this is an imperative.

Later articles regarding China show the need for better waste source separation, and when developing systems we need to take account of changing waste streams and mixtures as communities adopt new products, forms of employment and new industry practices are developed. None of this is static.

Secondly, the Circular Economy is a large concept that entails almost all aspects of what we do in an industrialised society. Many of the interventions are covered in the various chapters; however, there are some fundamental interventions which are and will be crucial:

- The role of innovation – at all levels – from materials design and use, to new ways to utilise waste materials to replace traditional virgin materials in production processes (Chapter 15).
- Biosolids: these shouldn't be overlooked and contain many nutrients and materials that will be in short supply. We need to far better utilise these resources (Chapter 4).
- Our behaviours and relationships with things is intriguing, and requires more work so as to unravel the complexities of our motives for consuming more. Why do we still chase fast fashions? We need to understand the social value of articles, products and services (Chapters 1 and 5–7).
- Transparency, and better data and better governance. This is fundamental to unmasking facts, data, and distilling solutions. The age of the internet of things and big data will make this easier (Chapter 16).

- The circular economy is not limited to businesses, but involves households, not-for-profits, cooperatives and other models, and it is equally applicable to water resources (Chapters 4 and 17).
- Easy to understand concepts are important if we are to engage with the public in the change to the circular economy (Chapter 9).
- The circular economy applies across all waste streams, and construction and demolition waste is no exception, and this is an important area of focus as it will also save construction time, and costs (Chapters 13 and 19).
- Circular economy principles apply to not only large countries like China and Australia but also places like Samoa (Chapter 11).
- Distributed production systems such as 3D printing will play a role in remote and small communities (Chapter 11).
- We will need regulation to be a part of the solution, extended producer responsibility and requiring design for disassembly and repair are intrinsic to where communities need to be (Chapters 1, 12, 18 and 19).

There are no more continents to conquer and in the case of Antarctica, we rightly question if we should. Our traditional linear systems are under challenge. However, this is the opportunity that needs to be grasped, to change the wasteful ways of the recent past and to be more innovative.

We are at this time in our history presented with so many choices, from what to wear and to eat, to mobility and technology, which drugs to take to make us healthier and live longer. We are inundated with information, but without the skills and knowledge to separate fact from fiction, and to make the appropriate choices in a complicated multifaceted consumer environment.

I feel we have the technology (for the most part), the capabilities and the time to bring about the necessary changes, despite the inertia sometimes apparent in the media and political sphere.

The United Nations, OECD, the Club of Rome and various governments across the world have developed case studies, tools, policies, tax regimes, economic instruments, legislation, communication tools and voluntary instruments. We have what is required. We know what needs to change; however, we oversimplify the human barriers to change.

With the rise and rise of artificial intelligence, machine learning and robotics, might we just be able to build trustworthy systems that help make all these choices easier for us, based on our personal genome, our economic situation, and simplify the regime of decision making for everyone? We are already dealing with big data and analysis, which potentially provides a global picture of population health, climate change and its impacts – can we harness the data to assist us to reduce waste and over-supply, reduce environmental impacts and become sustainable?

We can design out waste and redundancy, we have within reach new and different economic approaches and measurements that are more meaningful and can be employed to implement a circular economy. We have new business models that provide services rather than just material goods, and we can measure the economic value of the environment and the damage pollution causes.

We can do this, and it's likely technology will assist us. But we will need to be persistent, as this will take time.

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Note: Page numbers followed by "*n*" with numbers indicate notes.