Introduction

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The global economic model of value creation is wasteful and - for all practical purposes - continues to operate in a linear (take-make-dispose) system. Adopting Circular Economy principles could generate $4.5 trillion of additional economic output by 2030 whilst decoupling economic growth and natural resource consumption (Lacy P & Rutqvist J (2015))

Background

Since the late 2000s after the global economic crash, there has been growing discussion over Circular Economy (CE) at economic, societal and business levels. This followed on from longstanding – and sometimes forgotten - initiatives focused on resource efficiency and resource productivity that emerged in the 1990s in Japan, Germany and other European countries. The 1990s saw the publication of influential Factor 4 book (von Weizsäcker et al, 1998) focused on adding value through resource and energy efficiency, and increased policy, research and industry activity related topics such as 'extended producer responsibility', recycling and eco-design (including design for disassembly). Other catalysts to increased CE awareness emerged in the 2000s and included the publication of 'Cradle to Cradle' in 2002 (Braungart & McDonough, 2002) and the emergence of the Ellen McArthur Foundation in the early 2010s.

At a high level, CE can be seen as part of sustainable development and touches on a number of the United Nations Sustainable Development Goals (SDGs), in particular Responsible Consumption and Production. However, research has indicated that there is no universally accepted definition of CE (Kirchherr et al (2017)) with few explicitly linking the concept to sustainable development. This is a challenge for stakeholders, in that with no common context and perspective on CE, this means that policy makers, business and civil society may be talking at cross purposes. This may also be true in some countries that are taking a very broad definition of CE that seemingly includes renewable energy. There will be an increasing need for agreement over the terms and boundaries of CE, if substantial progress is to going made in policy, business and civil society. For example, is waste management and recycling in or out of scope of CE?

CE describes a world where maximising material use to its highest value over time in biological and technical systems is the prevailing economic and social model. The business opportunities that will emerge from CE are potentially huge but developing more circular product-service solutions will mean rethinking business models from design through (re)manufacturing, supply chain, (reverse) logistics to marketing and communications. Increased circularity will see design for maintenance, repairability, reconditioning, refurbishment, upgradability, remanufacturing, recyclability and compostability being fully integrated into business models, and product-service design and development processes.

However, it is important to recognise that the concept of CE is still evolving and may mean different things to different people at different levels in different countries. It is also important to remember that in many parts of the world there aren't even basic waste

management systems in place. A key topic then is how to design and implement new systems that focus on retaining materials value in the system for the longest time period that 'design out' waste from the beginning. This will mean that radical new policy frameworks will need to be developed to enable the extension of the lifecycle of products and packaging, and the components and materials within them.

Despite the evolutionary nature of CE, we may be moving towards a tipping point where there is a growing consensus in the global community about starting the transition away from the linear economy toward a more circular one. This is being driven by a range of issues including increasing global population, resource constraints and risks, policy changes, raising awareness, social and technological innovation, new materials and recognition of business opportunities.

CE activity is emerging at European Commission (EC) policy and standards levels, with new initiatives also emerging in the Netherlands and Finland, that go well beyond sector based extended producer responsibility initiatives and increased recycling targets. For example, a CE policy package was launched by the EC in December 2015 which has resulted in new standardisation activity related to repair, durability, remanufacturing and re-use. In 2018, China is revising its Circular Economy Promotion Law and Japan will move into the 3rd phase of its movement towards a Circular Society.

CE is moving into the boardroom – however, implementation is still at an early stage – and there is much to learn in relation to the implications for business models and product-service design and development. Against this backdrop, BS8001:2017 (BSI, 2017) was published in May 2017 to provide guidance on the implementation of CE in organisations. Whilst many of the components of CE have been in place in companies for many decades, what is new is the focus on retaining materials value in systems over time, eliminating waste at the design stage, and the need to take a systemic and coordinated approach to CE within organisations and value networks. Even companies taking a leadership position on CE have not yet, come up with comprehensive approaches. For most organisations, CE is likely to lead to a re-engineering or adaption of existing business models rather than development of new business models – unless there are major threats, risks or opportunities. Disruptive innovation is more likely to occur from start-ups and/or from new technologies or in response to societal change e.g. the 'Right to Repair' movement that started in the US is moving across to Europe.

CE thinking at a 'product level' or product circularly is focused on the use or *re-use* stage of the lifecycle and is fundamentally *not* about end-of-life. It is about proactively building into the design and development phase of products-services, strategies to enable maintenance, repair, refurbishment, reconditioning, upgrading, remanufacturing, parts harvesting and finally recycling. In CE terms, recycling should be thought of, as much further down the line, than in traditional lifecycle thinking. CE thinking should lead to an extended lifecycle perspective where materials are kept in the system to the highest value over the longest time period. However, a key issue is not to lose the lifecycle perspective and to become myopic e.g. trade-offs with other environmental aspects need to be considered. CE does not operate in a vacuum and is not a panacea.

Concept

The focus of "Designing for the Circular Economy" is not on CE at a macro-economic or materials flow level (e.g. global steel consumption and production), but at the company level and more specifically at business model and product level; although, inevitably they are inextricably linked.

"Designing for the Circular Economy" highlights and explores 'state of the art' research and industrial practice, highlighting CE as a source of: new business opportunities; radical business change; disruptive innovation; social change; and new consumer attitudes. The target audience for the book is academia and business with an interest in CE issues related to products, innovation and new business models.

The thirty-four chapters provide a comprehensive overview of issues related to product circularity from policy through to design and development. Chapters are designed to be easy to digest and include numerous examples. An important feature of the book is the case studies section that covers a diverse range of topics related to CE, business models and design and development in sectors ranging from construction to retail, clothing, technology and manufacturing.

The authors highlight innovative examples from a variety of practice in industries and businesses. Contributors illustrate the business, and design and development capabilities, thinking and skills that will be required to realise the potential opportunities resulting from a transition towards a more circular way of thinking. "Designing for the Circular Economy" aims to inform and educate companies, entrepreneurs and designers that are seeking to shift their business models, products and processes to align with the new paradigm. Organisations already working on CE, and those new to CE, will be able to benchmark their thinking and activities, and draw inspiration from innovative leaders, new applications and gain improved understanding of emerging business practice.

"Designing for a Circular Economy" is divided into five sections: Overview; Business Models; Design and Development; Technological and Social Innovation; and Case studies.

Section I: Overview

In Chapter 2, Stahel argues that a transition towards a Circular Industrial Economy (CIE) requires a paradigm shift from: consumers being motivated to be *consumers of products* to consumers becoming motivated to be *users of materials*; and companies shifting business models to sell *utilisation* rather than ownership. The chapter highlights emerging trends that support the premise that a movement has started from a Linear Industrial Economy (LIE) towards a CIE that includes: intelligent decentralisation; longer-life technologies; and re-usable high-technology. It is argued that central to the transition to the CIE will be a shift from the 'era of R' e.g. reuse, repair, etc to the 'era of D' e.g. de-linking assemblies, de-polymerisation, etc. Design will play a key role in the shift.

In Chapter 3, Charter highlights that CE is not a totally new topic and that it emerged from longstanding discussions over resource efficiency and productivity that started in Japan and Germany in the 1990s. The chapter highlights that there are many definitions of CE with no

one universally agreed and that CE should be viewed as part of a sustainable development. At product level, design for circularity should be considered within a broader eco-design approach and integrates an extended lifecycle perspective that focuses on (re)use rather than end-of-life. The chapter includes discussion on a range of current and emerging future issues that will impact on product circularity including policy, infrastructure, technology, the role of designers and materials.

In Chapter 4, Cumming references a number of 'schools of thought' that have fed into the emerging concept of CE and highlights where they differ. The practicalities of implementing CE within business are also discussed, as well as, the key challenges. The chapter highlights that many companies are still at an early stage in their CE thinking and implementation, and there is a need for guidance as there is still confusion, even over, the terminology and language of CE.

In Chapter 5, Benoy and Lehne give an overview over emerging developments in CE policy worldwide. The chapter highlights that CE type policies have existed for decades but the explicit use of the term in policy is relatively new with a lack of definitive approaches. A CE policy toolkit is presented and the chapter concludes with some thoughts about future development.

In Chapter 6, Cheng gives an overview of CE policy development in three Asian countries: Japan is the front runner of CE with comprehensive legislative and recycling systems; China is the second biggest economy and has an ambitious CE strategy; and Taiwan has transformed itself into a recycling powerhouse. In addition, the chapter presents a series of examples of innovative circular products and technologies from each of the countries.

In Chapter 7, Burgon and Wentworth give an overview of key issues associated with transitioning towards CE that includes improved product design, extended producer responsibility and new business models. An introduction to selected national CE policies is given with a specific example of the UK highlighted. Key challenges to achieving CE are illustrated with discussion over what needs to happen to achieve increased circularity.

In Chapter 8, O'Connor reflects on 25 years of experience related to circularity in design in the electronics sector. A case study is presented that compares activities in the 1990s to 2017 and questions whether substantial progress has been made.

Section II: Business models

In Chapter 9, Charter and McLanaghan discuss CE related business models. The development new circular business models has been closely aligned to many CE discussions; however, it is argued that for many organisations CE may lead to the adaption of existing business models rather than significant change unless there are major opportunities, risks or threats. Disruptive start-ups are likely to be those that will drive new circular business models. Circular business model groupings are described and illustrated with examples related to the potential re-use and recycling of polymer based fishing nets.

In Chapter 10, McAloone and Pigosso present a framework to support the design and development of product-service-systems (PSS) that consider CE. The components of the

framework are illustrated followed by a discussion of the development of PSS in a CE context.

In Chapter 11, Lindahl describes the issues surrounding CE focused product-service solutions based on an extended lifecycle perspective. An example of a CE focused product-service approach is given from a Swedish company that has shifted to re-using cores from paper rolls that had not previously been considered in the sector.

In Charter 12, Parker highlights market, business model and design issues associated with remanufacturing in the laser printing market. The case of Kyocera is presented, highlighting the company's approach to design for remanufacturing.

In Charter 13, Blomsma and Brennan describe two systems thinking tools that have been developed to support circular business modelling and product development. The Circular Compass identifies where waste is generated in systems and highlights three states of existence: particles, parts and products. The Circular Grid defines CE related relationships in systems in terms of cost, risk, dependency, infrastructure and knowledge. The authors suggest that applying Circularity Thinking will provide a better understanding of what CE strategies, business modellers or product developers might pursue.

Section III: Design and development

In Chapter 14, Bakker, Balkenede and Poppelaars put forward the concept of product integrity in the context of CE. In a CE, a product repeatedly cycles through the economy in different states of integrity. Two scenarios are presented that have very different implications for product integrity within a CE. 'Open loop, open source' focuses on the individual and collective role of citizens and consumers in CE, and 'closed loop, closed source' emphasises OEM control through access to business models in CE. Lessons are drawn from these scenarios for designers.

In Chapter 15, Brimacombe introduces the importance of integrating lifecycle thinking (LCT) into product circularity. There are illustrations of, for example, energy implications of CE decisions, trade-offs and the potential for unintended consequences if LCT is not considered. The concept of Social Value is introduced that highlights the importance of considering customer focused product use over time. The chapter also explores the challenges associated with short-term costs and investment required for product circularity versus the longer-term benefits.

In Chapter 16, Stevels discusses the evolution of eco-design that was initially focused on recycling and chemicals, and then became particularly targeted at energy reduction in 2000s. In the late 2000s there was re-emergence of concerns over the economics and supply risks associated with materials that led to a growing interest in CE issues. The concept of Design for Resource Value (DfRV) is introduced as a mechanism to incorporate CE considerations into eco-design and the need for new metrics is discussed.

In Chapter 17, Earley and Goldsworthy discuss emerging approaches to circular design in the textiles and clothing sector. Lessons from four practised-based research projects utilising

circular design approaches are discussed. Finally some insights into principles of circularity for designers are put forward.

In Chapter 18, Sundin introduces issues associated with design for remanufacturing. The chapter postulates the idea that products have three life stages - beginning, middle and end - and that CE places a greater focus on the *use* phase of the product. Design-related experience is also highlighted from four Japanese photocopier manufacturers that both manufacture and remanufacture.

In Chapter 19, Keiller and Charter highlight recent repair-related policy developments and the emergence of community repair organisations including repair cafes. Lessons are drawn from data derived from the repair activity of a repair café and the implications for design and development are discussed.

In Chapter 20, Chapman and Chalaris highlight the growing interest in design for CE in business but that few design schools have taken this on board. The chapter particularly focuses on collaboration between researchers from a design school and an international retailer that covered CE related topics. Experience from the project illustrates, for example, that academia and business operate in different time frames and that hybrid approaches need to be developed if such collaborations are to be successful.

Section IV: Technological and social innovation

In Chapter 21, Hunt provides an introduction to Industry 4.0 (I4.0) – cyber-physical-systems - and highlights the implications for CE. The future impact of I4.0 enabling technologies on CE and the implications for designers are explored and are illustrated with a series of examples.

In Chapter 22, Terizioglu illustrates how 3D printing (3DP) can be used to repair products and shows the potential for the technology to support product life extension. The chapter is based on the lessons learnt from twenty experiments with different products that illustrate the key issues and challenges related to 3DP and repair.

In Chapter 23, Prahl gives an overview of textile-based wearable technologies and emerging CE challenges including potentially short product lives and that the category falls outside of present ‘producer responsibility’ legislation. The need to bring in circularity into the design and development of wearable technologies is discussed and practical steps are proposed.

In Chapter 24, Kohtala highlights that at present, the development of makerspaces is weakly aligned to CE and broader sustainability issues; and that designers and non-designers involved in makerspaces are often more interested in ‘cool’ new technologies and materials. There is discussion over how makerspaces might become more circular.

In Chapter 25, Charter and Keiller discuss the emergence of repair cafés – community-led workshops – focused on repairing products, particularly consumer electronics and clothing. Results of a global survey highlight the high levels of repair being completed by skilled volunteers at repair cafes worldwide, the likely future growth of community repair and the implications for urban repair eco-systems.

Section V: Case studies

In Chapter 26, Hilton discusses the implications of the growth in returns of consumer electronics in the UK retail sector that are predicted to continue due to the increase in online sales. The chapter highlights a series of strategies that both manufacturers and retailers could pursue to improve product circularity of electrical and electronic equipment (EEE).

In Chapter 27, McIntyre describes how HP is driving CE into its core strategies and its supply chain. Three key areas are highlighted: closed loop recycling; product as a service; and 3D printing. Finally, a series of recommendations for progressing CE in organisations are introduced.

In Chapter 28, Wiens gives an overview of the issues and challenges associated with the repair of EEE. The background to the development of iFixit – a US-based open-source repair company - is discussed and how the firm has adapted its business model to the EEE market that is generally not implementing circularity in product design. This illustrated by how iFixit has had to innovate to access spare parts and develop its own tooling to enable repair.

In Chapter 29, Vildasen discusses a case study on Plasto – a Norwegian plastics products company – who set up a pilot project to use recycled plastic in a product working with a customer in the aquaculture sector. The case illustrates a range of issues including: the need for senior management commitment; importance of external feedback; perceptual challenges amongst internal and external stakeholders related to use of recycled materials; and the technical challenges of using recycled plastics in existing production equipment.

In Chapter 30, Khoo describes Interface's journey and lessons learnt in relation to circular materials innovation in its carpet tiling products. The set-up, implementation and learning from the NetWorks project – using waste nylon from fishing nets - is discussed in detail. Finally, a series of recommendations for CE innovators are proposed.

In Chapter 31, Baker-Brown reviews a number of CE cases from both the product and building worlds and highlights common issues such as the need for materials innovation. Examples are given of how architects are developing new approaches to the re-use of buildings, products, materials and components which is also leading to, in some instances, the development of new business models.

In Chapter 32, Durmisevic highlights that most building and construction is still focused on 'design for demolition'. The chapter discusses the need for and practical implications of implementing Reversible Building Design highlighting that 'design for disassembly' and reuse of buildings, systems, products, materials and components is new for this sector.

In Chapter 33, Andrews, Grussa, Chalk and Bush provide a case study on the blind and shutter sector in the UK. The chapter highlights that there is evidence of existing repair and refurbishment of these products in the UK market but that circularity needs to be improved substantially if fewer products are not going to end up in landfill. The chapter highlights a number of design improvements that the sector could take to improve product circularity.

In Chapter 34, Luscuere and Mulhall discuss the evolving concept of Materials Passports in the buildings sector. The chapter illustrates the need for improved product circularity information systems that are accessible to stakeholders through the lifecycle of buildings. The chapter emphasises that if circularity is to be accelerated in the building sector that new systems need to be developed to collect and disseminate CE data and information throughout the lifecycle.

Future issues

The concept and application of CE will continue to evolve worldwide. Policy tools will be deployed to stimulate circularity in Europe, Japan and China. There is an increasing global population and urbanisation worldwide, and cities will play a key role in driving CE. Companies will respond to external drivers and CE will increasingly drive innovation in products, technologies and materials. Large companies will adapt business models, processes and products, and CE will act as stimulus for a number of disruptive start-ups. Technology will be increasingly integrated into products and will create growing problems at end-of-life if circularity is not considered at the design stage. A range of social issues surrounding product circularity will emerge such as growing discussion over the "right to repair" and built-in product obsolescence. There will be continued growth in places and spaces to enable collaboration in making (makerspaces), modifying (hackerspaces) and fixing (repair cafes). Community and self-repair of products will increase enabled by collaboration, online video content and 3D printing utilising open data access to design files of spare parts. Industry 4.0 enabling technologies will move from discussion into application and will enable product life extension through smarter maintenance via embedded sensors and increased disassembly, repair and remanufacturing through new types of robots. The precise vision for 2030 and 2050 is unclear but it is clear that CE has a role to play in a more sustainable future.

References

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