SKILLS AND CAPABILITIES FOR A SUSTAINABLE AND CIRCULAR ECONOMY: THE CHANGING ROLE OF DESIGN

Irel Carolina De los Rios[a], Fiona J. Charnley[b]*

[a] Cranfield University
School of Aerospace Transport & Manufacturing
College Road, Cranfield, MK430AL
United Kingdom

[b] Cranfield University
Centre for Creative Competitive Design
College Road, Cranfield, MK430AL
United Kingdom

**Corresponding Author E-mail: f.j.charnley@cranfield.ac.uk*

Word Count: 8011

SKILLS AND CAPABILITIES FOR A SUSTAINABLE AND CIRCULAR ECONOMY: THE CHANGING ROLE OF DESIGN

Abstract

Implementing practices for a circular economy transforms the way companies do business, notably in the manufacturing industry. However, a circular economy requires a transformation of both production and consumption systems; the standard approach for creation, fabrication, and commerce of products is challenged. Authors repeatedly call for the development of new proficiencies to attend to system transformations, but these so far have not been described for design and engineering. Given that the design of a product directly influences the way a value chain will be managed, building circular, globally sustainable value chains inevitably signifies a fundamental change in the practice of design. Comprehensive analyses were conducted on case studies from a variety of multinational enterprises that are transforming their product strategies for climate change. Changes in design processes were identified, revealing a growing necessity for industry to employ new proficiencies that support closure of material loops. This paper contributes to existing literature by depicting successful practices being implemented in industry. A variety of new capabilities are key to design for a sustainable future; these range from deeper knowledge of material composition to rich understanding of social behaviour. Resulting from this research, learning goals are proposed to serve as guidance for manufacturing companies seeking to tackle climate change. Conclusions aim to encourage researchers and academics to respond to emerging needs by re-thinking education in design and engineering.

Keywords: Circular economy, closed loop systems, design for lifecycle, sustainable strategy, sustainable product-service system (SPSS)

List of Abbreviations

B2B *Business to Business*
B2C *Business to Consumer*
BAU *Business as Usual*
CE *Circular Economy*
Df *(Suffix) Design for*
DfX *Design for 'X' purpose / Design for Excellence*
EOL *End of Life*
FMCG *Fast Moving Consumer Goods*
LCA *Life Cycle Assessment*
MDM *Multilevel Design Model*
MNE *Multinational Enterprise*
NGO *Non-Governmental Organisation*
PLC *Product Life Cycle (i.e. from raw material extraction to end-of-life)*
R&D *Research and Development*
UI *User Interface*
UX *User Experience*

1. Introduction

Changes are taking place worldwide in business strategy as industries face increasing pressures from economic crises, resource scarcity and pollution. Material scarcity leading to rising costs, and recently introduced regulations for extended producer responsibility in the European Union have rendered sustainability strategies increasingly appealing to Multinational Enterprises (MNEs) (Dobbs et al., 2011; Ongondo et al., 2011).

Many different approaches to sustainability have been explored for the manufacturing industry, but despite efforts to reduce their carbon footprint, a large amount of enterprises continue to operate in a take-make-dispose rationale (Abdul-Rashid et al., 2008). Due to the speed at which the planet's resources have been exploited, an industrial evolution to effectively extend usable value of material assets is crucial to sustain human activities in years to come (McDonough and Braungart, 2001; Allwood et al., 2011).

Implementing holistic sustainability strategies inherently involves changes from the very creation of a product or service (Nakajima, 2000). The characteristics of a product directly influence the way the entire value chain will be constructed and managed (Bevilacqua et al., 2008), therefore design has a crucial role in supporting closed-loop supply chains and shared ownership models for sustainability (Nasr and Thurston, 2006; Souza, 2013).

Systemic transformations can be hindered when some actors involved are not aware of the role they are expected to undertake (Senge et al., 2007), especially when it comes to execution. Research has demonstrated that companies must build new capabilities to operate within sustainable industrial systems (Alix and Vallespir, 2010; Kopnina, 2014). Therefore, there is a need to inform education providers, product creators and industry stakeholders on how global manufacturing and commerce strategies for climate change will transform the practice of design.

1.1. The Circular Economy as a Pathway to Product Sustainability

The Circular Economy (CE), also known as a 'closed loop' economy, is an industrial and social evolutionary concept that pursues holistic sustainability goals through a culture of no waste. It emerges from ideologies introduced as long ago as 1862 with 'Waste Products' by Simmonds, 'The Economics of the Coming Spaceship Earth' by Boulding (1966), 'Industrial Ecology' Ayres and Kneese (1969) and more recent concepts such as 'Cradle to cradle' by McDonough and Braungart (2002), the 'Performance economy' by Stahel (1997) and 'Biomimicry' by Lovins et al. (1999), amongst others. In a CE, the end-of-life stage of products and materials must be replaced by restoration. The CE also regards industries shifting towards the use of renewable energy, the elimination of toxic chemicals and waste whilst maximising competitive advantage through the superior design of materials, products, systems and business models (Ellen MacArthur Foundation, 2012).

Enterprises that have subscribed to a CE reportedly benefit mainly from material savings, reduced supply risks, improved customer loyalty and the development of new revenue streams (Winkler, 2011; Ellen MacArthur Foundation, 2014; Schenkel et al., 2015). The CE has also caught the attention of governments, researchers and NGOs as a plausible road towards sustainable social growth by 'closing loops' and renewing both biological and technical materials (Giutini and Gaudette, 2003).

The Ellen MacArthur Foundation (2013) summarises four principles of the CE as points of action to eradicate careless resource depletion and revitalise existing material value in industry:

1. Optimise the use of resources and energy throughout lifecycles.
2. Maintain products and components in use for longer.
3. Materials cycle through the system as many times as possible through cascaded uses.
4. Utilise pure materials for improving quality of post-life use.

Different kinds of product cycles take place within a circular economy. Some loops involve companies maintaining economic value of material assets during their entire lifecycles, avoiding products to end up in landfill for as long as possible; some others involve the adoption of resources that can be reintegrated into nature, or fed into another supply chain (Ellen MacArthur Foundation, 2012).

Focus	***Value Flows*** *(Ellen MacArthur Foundation, 2013)*	***Primary Source of Revenue*** *(Lacy et al., 2014; Bakker et al., 2014b)*	***Economic Activities to Close Loops*** *(Stahel, 2013)*
Services	Cycling smaller – using less energy and fewer resources	Profit from increased utilisation rate of products, enabling shared use/access/ownership.	Reuse and remarket of manufactured goods
		Profit from selling access to a product for a specific period of time or 'uses', and retaining material ownership.	
Manufactured products	Cycling for longer	Profit from providing maintenance services or sales of refurbished, remanufactured or repaired units	Product-life extension activities for goods
		Profit from repeated sales of consumables or services for a long-life product	
		Profit from selling high quality products with a long lifespan at a high price	
	Cascaded uses	Profit from recovering resources/energy out of disposed products or by-products from the same or other company, upcycling or recycling them.	Material efficiency / recycling molecules
Materials	Pure or regenerative cycles	Profit from providing renewable energy, bio based- or fully recyclable materials to replace single-lifecycle inputs.	

Figure 1: Categorisation of business making for CE according to value form, sources of revenue and economic activities.

Necessary organisational changes to foster a CE model of production and consumption primarily encourage changes in the way industries profit. ***Figure 1*** summarises such changes by illustrating the elements of economic activities within a circular economy, as found in literature. Authors consider the biggest challenges for manufacturing enterprises are to adopt the business models that aim to profit from existing resources and reduce new resource dependency through servitisation (upper half of ***Figure 1)*** (Roy, 2000; Tukker, 2013; Bakker et al., 2014*b*).

A significant number of publications highlight the importance of developing capabilities to support strategies for closed-loop supply chains through design (Rahimifard and Clegg, 2008; Plant et al., 2010). In fact, it has been suggested that designers now have the potential to influence consumer perceptions and consumption patterns to help industry and society move away from careless resource depletion (Andrews, 2015), but to do so, "design has to show that it does more than make superficial changes to products" (Madge, 1993, p. 161).

1.2. Climate Change Challenging Design

Sustainable product design strategies that respond to climate change are far from being new topic in research. An exploration of available literature was conducted to identify existing design approaches for climate change strategies. A broad variety of design methods were found, often with shared rationale and goals.

Authors consistently encourage the use of Lifecycle Assessment (LCA) tools as key to enable producers and designers to assess the life costs of a product and subsequently manage material choices for ecological optimisations (Hertwich, 2005; Van Nes and Cramer, 2006). The implementation of refurbishing and remanufacturing at large scales has been thoroughly explored as a means to extend the life of electrical and electronic goods and motor vehicles. Consequently, design guidelines aiming to improve ease of disassembly, material separation and reassembly for circular products have been a fruitful topic of research (Hatcher et al., 2011; Crul et al., 2009).

Typically, design strategies for climate change are found under umbrella terms such as eco-design, design for the environment and sustainable design. A more descriptive classification was needed to clarify concepts for the reader, and aid forthcoming stages of the research. Thus, the categorisation shown in ***Table 1*** was elaborated. Go et al. (2015) produced definitions and guidelines of most methods related to designing products for multiple lifecylces, which enabled identifying the focus in the design process; the research by MacDonald and She (2015) helped to segment strategies according to the approaches to achieve holistically sustainable design.

Existing tools and methods are indeed effective to support decision making when aiming to foster sustainable product lifecycles (PLC) (Ilgin and Gupta, 2010). The Circularity Indicators Methodology is perhaps the most useful tool to support designers, and companies more broadly, to assess how well a product or company performs in the context of a CE allowing companies to estimate how advanced they are on their journey from linear to circular (Ellen MacArthur Foundation, 2015). However, Tukker (2013) and Bakker (et al., 2014*a*) consider that design efforts to increase resource sufficiency need to be further focused towards assessing intangible value and influencing consumer acceptance of new ownership models. It was found that the majority of design for sustainability tools and guidelines only concern themselves with the technical design criteria, disregarding the bigger picture related to corporate strategies for sustainability.

APPROACH	FOCUS	STRATEGY	DFX / METHODS
WHOLE SYSTEMS DESIGN	SUSTAINABLE SYSTEMS	Radical innovation for sustainability	
DESIGN FOR ENVIRONMENT (PREVENTIVE)		Reduced environmental backpacks	Design for Supply Chain
	ENERGY CONSERVATION		Design for Manufacturing and Assembly
		Clean energy consumption	Biomimicry
	MATERIAL CONSERVATION	Material selection for sustainability	
DESIGN FOR LIFE CYCLE	DESIGN FOR EXTENDED LIFE (LONGER LIFECYCLES)	Design for Reliability	Design for Quality
		Design for Maintenance	Design for Repair / Refurbishment
		Design for Reuse	
			Design for Upgrading
	DESIGN FOR END-OF-LIFE (MULTIPLE LIFECYCLES / CRADLE TO CRADLE)	Design for Component Recovery	Design for Remanufacturing
		Design for Material Recovery	Design for Recycling
			Design for Cascaded Use

Table 1. Taxonomy of design approaches for a sustainable industry.

Most solutions to implement and maintain a sustainable industry are inter-sectoral and interdisciplinary (Lozano, 2012), and concurrent teams are a common approach for sustainable product development and whole systems design. However, research has highlighted issues with this approach when knowledge is compartmentalised and key information cannot be properly transmitted (Boehm and Thomas, 2013; Vezzoli et al., 2015), and pointed out a need to develop new transdisciplinary capabilities to avoid increasing product development time and complexity (Zwolinski and Brissaud, 2006; Vasantha et al., 2012). It still remains to be clarified what kind of capabilities should be cultivated in designers.

While it has been established that a change of mind-set driven by environmental awareness is required from design practitioners (Roux, 2011; Andrews, 2015), an investigation has not yet been made into the necessary capabilities required to execute both technical and strategic changes in design for the CE (Hatcher et al., 2011). Furthermore, most of the literature is academic or with industrial examples mostly from business-to-business (B2B); this reveals a lack of evidence in the ways design could be changing within other industrial and market systems.

Having found such gaps in current literature, this research aimed to *aid in understanding how technical changes in products, summed to the transformation of industrial systems contribute to shape the discipline of design within sustainable models of production and consumption*. In order to do so, a thorough exploration was conducted on case studies comprising MNEs from consumer electronics, fast moving consumer goods, furniture, and automobile industries. From these, six case studies are comprised by MNEs and two more by local enterprises. Said analysis had the objective to explore technical and non-technical factors involved in developing a variety of circular products and services in order to build theories to respond the questions *a) How is the role of design changing with sustainable business strategies when compared to business-as-usual?* and *b) Which are design competences required to effectively perform within sustainable business models*?

2. Methods

Case study research has been considered a suitable approach to build theories on a new topic concerning contemporary events (Eisenhardt, 1989; Yin, 2009). It served to the purpose of depicting successful practices implemented in industry, which Vezzoli et al. (2015) and Tukker (2013) considered of utmost importance to encourage application of the existing body of knowledge regarding systemic transformations for industrial sustainability. Case studies were gathered from the databases of the Ellen MacArthur Foundation (as of June 2015) and the consultancy Accenture© (as of June 2015). To overcome the limitation of using case studies derived from a secondary data source, the data collected and findings deduced were further validated, where available, through direct interactions with practitioners within the case study organisations and those organisations who published them. Secondary data was also collected from press releases, in addition to the web pages of the companies studied, to enable a comprehensive picture of each case study to be developed and to avoid reporter bias. The quantity of information collected through use of this approach alongside the accuracy of inferences made, confirmed by a range of consulting experts, was deemed comparable to undertaking first hand case study research and justified the deductions made.

As prescribed by Eisenhardt (1989), selection of the cases to study was based on a set of criteria resulting from a preliminary theoretical framework:

- Manufacturing companies were considered most relevant, given these are especially challenged when transforming for sustainability (Stahel, 1997).
- Case studies must exemplify a variety of strategies for climate change. The role of design within different business models should be analysed, therefore the categorisation by Lacy et al. (2014), was used as a guide to select exemplary case studies.
- Case studies must illustrate applications of circular economy in a wide variety of products and life-spans; from long-life, costly products to 'fast moving consumer goods' (FMCG) and single-use products.
- The analysis should include examples of business-to-business (B2B) and business-to-consumer (B2C) markets.

The *Multilevel Design Model* (MDM), proposed by Joore and Brezet (2015) to aid systemic analysis, is claimed to be useful in determining potential contributions from design both for tangible and intangible outcomes. Therefore, it was considered suitable as a tool for content analysis in a systematic manner, ensuring relevant data was collected and keeping a consistent multiple case study analysis (Eisenhardt, 1989): *Reflection* to present the characteristics of the initial situation within the context of the case study. *Analysis* to describe the objectives and drivers supporting the transition to a CE. *Synthesis* to list the developments made within the company's system. *Experimentation* to describe the solutions generated or pursued by the companies in each case, to achieve business sustainability. As a result, changes in the role of design, as well as influencing factors within each scenario could be depicted.

The role of design was translated into abilities and skills using the evidence from case studies, and cross-referencing design requirements in each scenario with a literature framework concerning Design for X (DfX) strategies, as suggested by Eisenhardt (1989) and Yin (2009).

Firstly, the results of the MDM analyses were presented as an electronic draft to stakeholders from the companies studied (see ***Table 2***) where available, and to experts involved in organisations that conducted the original case study. Confirmation of the accuracy of the Multilevel Analysis and additional input to fix inaccuracies was obtained in the process.

Secondly, a report was formulated for each case study containing a description of the role that design appeared to play, and a list of capabilities required to fulfil said role. These reports were also submitted to and validated by the relevant experts, which provided a layer of robustness to the findings.

Table 2: Panel of validating experts.

Role	Company / Organisation
Chief Executive Officer	Rype Office®
Program manager Circular Economy	Royal Philips
Design director	Ecovative
Sustainability Developer	Ikea
Head of Innovation	Ellen MacArthur Foundation
Lecturer and researcher	NHL University of Applied Science
Circular economy researcher	Delft University of Technology

Resulting from this research methodology the implications of creating products suitable for climate change were explored and analysed, and thus it was possible to formulate learning goals for designers to support sustainability strategies within MNEs.

In order to scale the findings to a generic panorama of the circular economy, outcomes from the multiple case studies were compared (Yin, 2009). Practical and theoretical evidence was used to make connections, differentiate findings and reach conclusions on the requirements for the designers of a sustainable industrial system.

3. Results: Analysis of CE Strategies Implemented in MNEs

3.1. Audi®: Sharing Platform for Automobiles

The case of study is Audi Unite™, the car sharing service branch of Audi®, which not only represents efficiency in the use of materials for automobiles, but also advocates for reducing the amount of vehicles on the road. In this access-based model, the ownership of the car and remains within the manufacturer (Audi, 2015). The car then becomes a capital investment for Audi, therefore it is in their best interest to develop reliable products that can be easily maintained and re-used. The different levels of the approach taken by Audi® for providing a product-service for share were identified and summarised in ***Table 3.***

Table 3: System analysis of Audi Unite™ platform. (*Data sources: Audi, 2015; Audi AG, 2015abc*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	The automobile industry is particularly pressured to reduce their carbon footprint at all stages of the product lifecycle. But usage is normally out of the manufacturer's control.	Reduction of carbon footprint and increment of responsible car usage.	Development of initiatives to promote responsible use of fossil fuels.	Car sharing helps reduce the number of cars on the road, meaning fewer CO2 emissions are polluting the air.
SOCIO-TECHNICAL SYSTEM System innovations and market	The concept of material ownership as a measure of wealth and wellbeing is still rooted in modern society.	Promotion of shared ownership schemes through an attractive product-service offering.	Development of specialised service strategies as well as relevant supply relationships to support the car sharing scheme.	Cars are shared amongst friends and the service includes full insurance, monthly cleaning, and fuel cards.
PRODUCT-SERVICE SYSTEM Business and process innovations	Since its origins Audi® has been a pioneer of technical innovations in the automobile market, and has one of the most flexible and efficient production systems.	Creation and adoption of technological innovation in services and products, as key differentiation from other brands.	Development of cleaner production systems and engine technologies. Development of UX tools like personalised apps to support the product-service system.	The latest Audi® models are offered with an app and a beacon to manage bill sharing, scheduling and connect users, automobile and service provider.
PRODUCT-TECHNOLOGY Product innovations	Customers buy an Audi® for its design. The latest technologies in terms of mechanical innovations, assisted driving, materials and aerodynamics are researched and developed in Audi®.	Foment desire and use experience to support alternative ownership and aftermarket of cleaner technologies. Compatibility with optimised production processes.	Design for improved user experiences and customisation alternatives. Development of automobiles in standardised platforms.	Product technologies for easier management and enhanced user experience of shared units. Automobiles that ensure quality for long-life and extended use.

3.2. Nokia®: Products as a Service for Mobile Devices

Leasing is a strategy under development for creating a CE in Nokia® (Accenture, 2013), allowing Nokia® to maintain ownership and control the lifecycle of their products to comply with regulations. Product design strategies must drive customers to prefer leasing Nokia® mobile phones over owning the competitor's products. For enhancing the service experience, designers must understand the requirements and expectations from customers as well as the optimal lifespan of the product based on technology (Tukker, 2013; Bakker et al., 2014*a*). ***Table 4*** depicts the multilevel aspects of this climate change strategy.

Table 4: System analysis of Nokia® leasing scheme. *(Data sources: Accenture, 2013).*

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Mass consumption and reckless disposal of products have led to severe pollution.	Reduction of pollution caused by disposal of dangerous materials contained in WEEE.	Implementation of regulations like WEEE worldwide to improve collection and management of electronic waste.	Circular economy models permit manufacturers to obtain benefits from savings by recovering rare and scarce materials.
SOCIO-TECHNICAL SYSTEM System innovations and market	A large percentage of devices are unofficially disassembled in the second-hand market. Great variation of motivations for customers to acquire new mobile devices.	Increase returns of EOL electronic equipment to the manufacturer.	Development of reverse supply chains and collaboration with other manufacturers and operators to support alternative product-service propositions.	Implementation is still being tested, requiring significant effort in industry change.
PRODUCT-SERVICE SYSTEM Business and process innovations	Mobile communication products still hold value at the end-of-life, but Nokia® has very little visibility of material flows in the aftermarket.	Improvement in the control of material flows during product lifecycle and at the end of it.	Accenture® developed a leasing business model for Nokia® to ensure returns of products.	Mobile devices would be offered to the consumer as a tool for the function, while the ownership of material assets is retained by Nokia®.
PRODUCT-TECHNOLOGY Product innovations	Mobile smart devices are amongst the products with highest innovation pace and shortest lives. Electronics contain complex, often expensive cores composed from a blend of materials.	Motivate customers to prefer leasing Nokia® products over owning the competitor's products. Support recovery of materials at EOL.	Design for improved user experiences. Product design to facilitate disassembly and material separation and recovery.	Products with high value perception, both initial and for the aftermarket. Easily diagnosed, and suitable for disassembly and material separation.

Table 5: System analysis of Rype Office® furniture (*Data sources: Ellen MacArthur Foundation, 2015d; Rype Office, 2015*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Valuable materials are lost when furniture reaches its EOL causing severe landfill issues.	Increase in the usage of furniture, and elimination of material value lost to landfill.	Development of consumer awareness and regulations to extend the life of products and reduce resource expenditure.	Circular economy models permit manufacturers to obtain benefits, while reducing the amount of materials going to landfill.
SOCIO-TECHNICAL SYSTEM System innovations and market	Customers consider pay-per-use models more expensive or inconvenient due to lack of ownership. Customers are also wary of remanufactured goods.	Introduction of circular products by allowing customers to adopt sustainable products or alternative ownership models gradually.	Development of product and service propositions that maximise economic, environmental and social value for customers.	Rype Office®, offers design services with three options for their customers: *Refresh* their existing furniture, receive *New* furniture or *Remade* furniture.
PRODUCT-SERVICE SYSTEM Business and process innovations	Rype Office® was born as a dynamic furniture remanufacturing business specialising in office furniture.	Provision of products and services that are customised to suit individual client needs, to foster acceptance.	Management of a variety of suppliers and on-site and outsourced capabilities, to ensure capacity to serve large orders and diverse furniture types.	Rype Office® recovers furniture for remanufacturing at the end of its first life, provides customised design services and repairs existing furniture.
PRODUCT-TECHNOLOGY Product innovations	Design within Rype Office® is primarily provided as a consultancy service and products are made-to-order.	Design of furnishings for multiple life-cycles and high customisation.	Design for cost effective remanufacture, including ease of assembly and disassembly. Design and selection of a range of building blocks from available feedstock.	Rype Office® provides customised furniture of a timeless aesthetic. Suitable for maintenance and reuse, efficient assembly, disassembly and re-manufacture.

3.3. *Rype Office®: Products as Services and Life Extension for Office Furniture*

The usable life of furniture is dictated by enterprise owners and not users. Second-hand market for furniture is widely disseminated, but generally unappealing for the high-end customers and it seldom has the ability to supply large quantities of office furniture for enterprises (Rype Office, 2015). Rype Office® is a UK growing enterprise that approaches the furniture market with a different strategy; it aims to maximise economic, environmental and social value for customers by remanufacturing custom or existing furniture and offering a guaranteed buy-back price or lease option (Ellen MacArthur Foundation, 2015*d*). Rype Office®'s multilevel impact of their business strategy is shown in ***Table 5***.

3.4. *Philips Health™: Product Life Extension for Medical Equipment*

Medical imaging products represent high investments in and long R&D processes in companies as Philips®. Despite technology advances, healthcare budgets are increasingly under pressure and care facilities seek to make use of diagnostic equipment for long periods of time, but their life-saving character demands optimal reliability (Philips, 2014). Philips® proposes two forms of business for circular products: the first is pre-owned refurbished units. The second is a new service business model for medical equipment where clinics would pay for the use of the latest medical technology, while Philips® retains ownership. Stated by Philips® (2014), modular design approaches will be used for new products. The objective is achieving highly reusable subassemblies and maximise residual value of products and facilitate parts harvesting procedures (Philips, 2014). Different levels of Philips® sustainability strategies are depicted in ***Table 6***.

Table 6: System analysis of Philips® refurbished systems (*Data sources: Philips, 2014; 2015*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Disposal of man-made materials and dangerous waste have led to severe landfill and pollution.	Reduction in pollution caused by reckless disposal of dangerous materials contained in WEEE. Reuse of scarce and expensive materials.	Implementation of regulations like WEEE worldwide to improve collection and management of electronics waste.	Circular economy models permit manufacturers to obtain benefits, while complying with regulations and providing customers with the results they require.
SOCIO-TECHNICAL SYSTEM System innovations and market	Healthcare budgets increasingly under pressure; facilities are looking to extend the life of their resources, whenever new equipment is not strictly necessary.	Introduction of solutions that fit in a restricted budget through leasing schemes and refurbishment.	Development of service business and refurbished product propositions, fostered by creation of client relationships and collaboration for reverse logistics.	Philips® is buying back and re-marketing pre-owned products. Maintenance and repair of the equipment, as well as technology upgrades are included in new access contracts.
PRODUCT-SERVICE SYSTEM Business and process innovations	Philips® has refurbished lines of medical imaging products which have found an increasing demand in the last 20 years.	Expansion of the business for refurbished and remanufactured systems.	Development of infrastructure via a Refurbished Systems factory, to support product life extension activities and circular material flows.	Philips® refurbishes and upgrades expensive medical equipment for quality assurance. Parts harvesting from EOL equipment provides perfectly working spares.
PRODUCT-TECHNOLOGY Product innovations	Medical imaging products represent high investments in R&D from Philips® and its mechanisms contain valuable materials. Products have long lives and their life-saving purpose demands optimal reliability.	Maximise product life, re-use and residual value.	Design to boost durability through maintainability. Design for and from reusable, standardised and modular components, to facilitate production, upgrade and refurbishment	Philips® offers durable, reliable new and pre-owned healthcare products that can be easily maintained in optimal working conditions, and be efficiently upgraded for better performance.

3.5. *Steelcase®: Product Life Extension for Office Furniture*

Steelcase® continuously aims to develop products with better environmental performance and higher quality and efficiency in their operations (Steelcase, 2015). Further driven by environmental issues and embracing the Cradle to Cradle© philosophy, Steelcase® currently leverages for product design and development with a materials perspective (Steelcase, 2015). ***Table 7*** depicts their current strategies for closed loops.

Table 7: System analysis of Steelcase® furniture (*Data sources: Ellen MacArthur Foundation, 2015b; Steelcase, 2015*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Disposal of man-made materials and dangerous waste have led to severe landfill and pollution.	Reduction of pollution and elimination of health risks caused by materials used in living environments.	Increase of consumer awareness to reduce landfill, and regulations for use of polluting materials and waste take-back.	Manufacturers are increasingly aware of the EOL and during-use environmental impacts of their products, and are creating strategies to reduce them.
SOCIO-TECHNICAL SYSTEM System innovations and market	Furniture performance linked to "fashionable" factors. Valuable materials are lost when furniture reaches its EOL.	Avoidance of material value loss at the end of the furniture's desirable life, maximising value in the use of furniture.	Development of collaborations and partnerships with clients and retailers to support remarket, reverse logistics and EOL treatment.	Steelcase® is collaborating with retailers to implement programmes for end of use and reuse to extend their product's valuable life.
PRODUCT-SERVICE SYSTEM Business and process innovations	Steelcase® has a reputation for high quality solutions that encompass interior architecture, furniture and technology.	Promotion of wellbeing in the workplace without the use of chemical agents. Elimination of harmful effects from manufacturing processes.	Development of processes and tools to analyse product lifecycles and research in materials to improve environmental performance	Steelcase® uses insights from product LCA and applies new sustainable alternatives to continuously improve their PLC.
PRODUCT-TECHNOLOGY Product innovations	Steelcase® has been characterised for producing functional, sustainable and stylish products that improve the office environment.	Application of state-of-the-art technology to develop sustainable products that enrich the office environment.	Development of biomimicry products. Design supported by LCA and analysis of materials chemistry to ensure suitability for use and EOL re-processing.	Cradle to Cradle Certified^{CM} products embedded with high functional value from ergonomics to material technology. Steelcase® offers high quality, long life and high residual value.

3.6. *Splosh®: Product Life Extension for Packaging*

In short-lived Fast Moving Consumer Goods (FMCG), the functional value of the product remains in the consumable part of it, while the value of the package ends after a sale is made. Splosh® is a UK based enterprise that offers an alternative business model for household cleaning products, enabled by product technology, which aims for minimal environmental impacts and extended packaging lifecycles (Ellen MacArthur Foundation, 2015*e*). ***Table 8*** provides an analysis of their product system.

Table 8: System analysis of Splosh® cleaning products (*Data sources: Ellen MacArthur Foundation, 2015e; Splosh, 2015*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Landfill and water pollution issues due to reckless disposal of man-made chemicals and packaging waste.	Reduce pollution by supporting the use of environmentally compliant products and substances.	Development of regulations to reduce carbon footprint and environmental labelling, to avoid using highly toxic chemicals and palm oil.	Manufacturers addressing the environmental impacts of their products, and adopting substances that can be safely integrated in biological loops.
SOCIO-TECHNICAL SYSTEM System innovations and market	Short-lived FMCG products represent 75% of the waste going to landfill.	Improve sustainability of FMCG.	Creation of a supply chain alternative that reduces environmental footprint.	Splosh® minimises water cutting CO2 emissions by up to 95%. Refillable bottles avoid energy expenditure of recovery and recycling.
PRODUCT-SERVICE SYSTEM Business and process innovations	Cleaning products are judged upon performance, price and convenience. Typically purchased from retailers.	Provision of a sustainable alternative to competing cleaning products bought at the supermarket.	Development of product-service offerings that generate a better purchase and user experience, and attends to sustainability goals.	Purchases are made directly online in a user-friendly interface and posted for free in a letterbox sized package to suit customer convenience and cut retail costs.
PRODUCT-TECHNOLOGY Product innovations	Splosh® developed innovation in sustainable chemical formulations for cleaning products.	Extension in value of bottles, optimisation of logistics and improvement of chemical efficiency for sustainability.	Design of package for durability and attachment. Secondary package is produced focusing on logistics and recyclability.	Bottle design is durable and prevents customers from discarding it. Package design supports service in a resource-efficient manner.

3.7. Ikea®: Material Recovery for Home Furniture

Ikea® thrives to produce quality furniture at affordable prices for its customers by optimising their supply chain processes. Aside from their distinctive user assembled furniture, as a strategy for logistics optimisation, Ikea® is pursuing the use of waste as resources for new products, simultaneously reducing landfill by establishing take-back campaigns for recycling furniture. In addition to their process minimisation approach, designers will also require to wisely use recycled and biodegradable materials in a way that does not complicate recovery at EOL. ***Table 9*** contains an analysis of the developments made by Ikea® to reach a CE.

3.8. Ecovative®: Circular Supplies for Packaging

Ecovative® is a MNE that emerged from the creation of a mushroom-based material that was discovered to have properties similar to plastic foams, but being completely renewable (Ecovative, 2015*a*). Ecovative® uses a material-first design approach to enhance the functional and aesthetic performance of mushroom material packaging (Ecovative, 2015*b*). Design and adaptation of products from customers must be carefully assessed to ensure process compatibility (Ecovative, 2015*b*). ***Table 10*** offers a multilevel depiction of Ecovative® circular supplies.

Table 9: System analysis of Ikea® activities for material recovery (*Data sources: Canada et al., 2007; Ellen MacArthur Foundation, 2015a; Ikea, 2015*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Natural resources, such as wood, are extracted in large amounts for the furniture industry and are treated or altered, which prevents its safe degradation into the environment.	Reduction of resource depletion and landfill pollution.	Increase of consumer awareness to reduce landfill, and regulations for use of polluting materials and waste take-back.	Companies are increasingly addressing the reduction of resource extraction, their carbon footprint, and the elimination of hazardous chemicals from across their value chain.
SOCIO-TECHNICAL SYSTEM System innovations and market	Furniture performance is linked to "fashionable" factors. Valuable materials are lost when furniture reaches its EOL.	Reduction in the environmental impact of Ikea® large volume manufacturing.	Development of key resource chains to secure recycled materials and implementation of reverse logistics that support take-back policies.	Ikea® is sourcing circular materials and increasing the opportunities for its customers to recycle home furnishings at EOL.
PRODUCT-SERVICE SYSTEM Business and process innovations	Ikea® has strived to achieve product quality by building strong supplier relationships, producing large volumes and investing in efficient production technologies.	Ingrain the value of sustainability in Ikea® products and operations.	Development of state-of-the-art manufacturing facilities that use renewable energy and more resource efficient processes.	The company envisions to generate as much energy as consumed and become a leader in renewable energy. Ikea® is also leading efforts for turning waste into resources for new products.
PRODUCT-TECHNOLOGY Product innovations	The Ikea® business idea is to offer "a wide range of well-designed, functional home furnishing products at affordable prices	Optimisation of resource and material usage throughout the product life cycle	Design for efficiency in production and logistics. Selection of recycled, recyclable and biomaterials and development of knowledge to aid recovery at EOL.	Visually attractive and functional homeware and furnishings that can be sustainably produced. Ikea® aims to enable reintegration into technical and biological cycles for all materials used in their products.

Table 10: System analysis of Ecovative® (*Data sources: Ecovative, 2015a; 2015b; Ellen MacArthur Foundation, 2015c*).

	REFLECTION Initial State	**ANALYSIS** Requirements and targets	**SYNTHESIS** Developments	**EXPERIMENTATION** Implementation of CE
SOCIETAL SYSTEM Contextual landscape	Landfill pollution issues due to mass consumption and reckless disposal of man-made materials.	Elimination of toxic, polluting waste.	Development of regulations and environmental labelling to avoid using toxic chemicals and materials.	Manufacturers becoming aware of the environmental impacts of their products, and adopting substances that can be safely integrated in biological loops.
SOCIO-TECHNICAL SYSTEM System innovations and market	Short-lived FMCG products represent 75% of the waste going to landfill.	Replacement of oil-based materials used in packaging.	Development of partnerships and knowledge to design equipment and tooling for the production of Mushroom® Material.	Ecovative® materials can be safely reabsorbed by soil and can be suitable for production on any scale.
PRODUCT-SERVICE SYSTEM Business and process innovations	Ecovative® materials were developed to be renewable, bio-based and biodegradable.	Provision of alternative sustainable materials for industry, by meeting actual performance requirements.	Development of process innovation using low energy and yielding high quality.	Cost competitive and environmentally alternative to existing non-sustainable options.
PRODUCT-TECHNOLOGY Product innovations	Product-technology innovation is required to support and spread the use of new generation materials.	Generate new concepts and adaptation of existing product specifications to bio-based materials.	Material-first design approach, and development of specialised know-how to utilise Mushroom® Material.	Design of package and products that attract investors for further possible uses of the Mushroom® Material products that reintegrate into nature.

4. Findings

Table 11: Cross-case analysis of findings.

Case Study	**Business Model**	**The Role of Design**	**Priority Areas in PLC**	**Related DfX Strategies** (Holt and Barnes, 2009; Go et al., 2015)
Audi® – B2C	Sharing Platforms	Generate desire and foster durability. Facilitate use and maintenance. Facilitate optimised production. Boost service/use experience.	Manufacture, Sales, Use, Maintain	DfQuality DfReuse DfReliability DfMaintainance
Nokia® – B2C	Products as Services	Generate desire. Boost service/use experience. Retrofit and upgrade based on available materials.	Manufacture, Sales, Use, Upgrade, EOL	DfQuality DfReliability DfReuse DfAssembly/ Disassembly DfRecycling DfRemanufacture DfUpgradeability
Rype Office® – B2B	Products as Services and Remanufac-turing	Generate desire and foster durability. Retrofit and upgrade based on available materials.	Manufacture, Sales, Maintain, Upgrade / refurbish	DfQuality DfReuse DfMaintenance DfRemanufacture DfUpgradeability DfAssembly/ Disassembly/ Reassembly
Steelcase® – B2B	Product Life Extension *High-end and material innovation*	Generate desire and foster durability. Facilitate use and maintenance. Improve material performance.	Manufacture, Sales, Use, Maintain, EOL	DfEnvironment DfQuality DfReuse DfMaintainability DfAssembly/Disassembly DfRecycling
Philips® – B2B	Product Life Extension *Refurbish and upgrade*	Foster durability. Design modules suitable for multiple compatibility and future upgradeability. Facilitate use and maintenance. Retrofit and upgrade based on available materials.	Manufacture, Maintain, Upgrade / refurbish	DfQuality DfReliability DfReuse DfMaintenance DfRemanufacture DfUpgradeability DfAssembly/ Disassembly/ Reassembly
Splosh® – B2C	Product Life Extension *Consumables*	Generate attachment and foster durability. Facilitate logistics. Boost service/use experience.	Sales / distribution, Use, Maintain, EOL	DfEnvironment DfSupply Chain DfReuse Affective design
Ikea® – B2C	Material Recovery	Generate desire. Adapt to processes and facilitate logistics. Facilitate Recycling.	Manufacture, sales / distribution, EOL	DfEnvironment DfSupply Chain DfAssembly/Disassembly DfRecycling
Ecovative® – B2B	Circular Supplies	Improve material performance. Adapt to processes and facilitate logistics.	Manufacture, Use	DfEnvironment DfQuality DfSupply Chain

A theoretical framework was used to identify existing design methods that aim to fulfil the CE needs of the MNEs studied. Based on the empirical evidence gathered, the requirements of 'design for' (DfX) strategies relevant to each case study were identified, and the necessary knowledge from designers derived from this. These deductions were validated, as suggested by Eisenhardt (1989), by the stakeholders from the relevant MNE's and CE experts. ***Table 11*** provides a full cross-case comparison and description of the design skills validated as suitable for each business context.

Ten requirements for capability development were identified in this comparison as necessary to design products and services that support the many pathways to form closed loops of materials ***(see first column, Table 12).*** Adding new areas of knowledge to design curricula could be a simple prescription to cover the needs of a circular and sustainable industry. However, existing research highlights the need for product and service design that is suitable for the system and associated actors in which they will exist (Blizzard and Klotz, 2012; Joore and Brezet, 2015). Thus, segmentation was judged an appropriate approach to address skill-building for circular design.

Table 12: Design skills necessary to create products for closed loops.

Capabilities to leverage product design	Sharing Platforms	Products as Services	Product Life Extension (consumables)	Product Life Extension (high-end)	Product Life Extension (refurbish and upgrade)	Products as Services (Remanufacture)	Material Recovery	Circular Supplies
Understand logistics and distribution processes.			X				X	X
Understand the service experience and how to design services.	X	X	X					
Understand user expectations and perception of value.	X	X	X	X		X	X	X
Understand factors of the use experience.	X	X	X	X				
Understand product wear by use.	X	X	X	X	X	X		X
Assess material physical and chemical properties.				X				X
Understand engineering functions of the product.	X				X	X		
Understand failure mode and maintenance procedures.	X				X	X		
Understand processes for reverse and re-manufacturing		X		X	X	X	X	
Solve aesthetic and structural problems with limited supplied components.					X	X		

Findings were plotted in ***Table 12*** to determine any overarching skills or patterns in case studies. It was observed that some skills had patterns of complementing others, while others were mutually exclusive.

Designer profiles or ‘Design personas’ were formulated based on the various interactions of design roles found in the case studies, linked to business strategies. Resulting from this research findings, ***Table 13*** depicts designer archetypes needed for a circular economy, and proposes additional disciplines for designers to learn from.

Table 13. Features and applicability of the 'design personas' within CE business models and product types.

Design Persona		**Luxury UX designer**	**Product-service designer**	**Block-building designer**	**Retrofitting designer**	**Scientific designer**	**Green fixer**
Additional areas of knowledge		Social sciences and fine arts	Social sciences and management.	Engineering and manufacturing systems	Advanced engineering	Chemistry and biology	Ecology
Product type (Bakker et al., 2014b)		Long-life products with high quality and upfront costs.	Long, medium or short life products on alternative ownership and services.	Technologically mature products for refurbishing, remanufacturing or mass customisation.	Technological evolving products for upgrading and remanufacturing.	Cradle-to-cradle and biomimicry products of any life span.	Medium or short life products that do not imply a change of ownership.
Business model archetype	*Sharing Platforms*	**X**	**X**				
	Products as Services		**X**	**X**	**X**		
	Product life extension (provision of consumables)		**X**	**X**		**X**	
	Product life extension (high-end and reuse)	**X**				**X**	
	Product life extension (Refurbish and upgrade)			**X**	**X**		
	Products as Services (Remanufacture)	**X**		**X**	**X**		
	Material Recovery	**X**				**X**	**X**
	Circular Supplies	**X**				**X**	**X**
Market type	B2B			**X**	**X**	**X**	**X**
	B2C	**X**	**X**		**X**	**X**	**X**
The service experience and how to design services.		**X**	**X**				
User expectations and perception of value.		**X**	**X**		**X**		**X**

Customer's interactions with the product and UX.	x	x			x	
Product wear by use.	x		x		x	
Logistics and distribution processes.		x	x			x
Engineering system of the product.			x	x		
Failure mode and maintenance procedures.		x	x	x		
Processes for reverse and re-manufacturing			x	x	x	x
Solving aesthetic and structural problems with limitations of supplied components.			x	x		
Perform lifecycle assessments.	x	x	x	x	x	x
Assess material physical properties.	x		x	x	x	
Assess material chemical properties.					x	

5. Discussion

The need to construct proficiencies for sustainable design for a closed-loop industrial system had been thoroughly highlighted by literature. Contemporary research has demanded mind-set changes and proposed DfX guidelines, but made no specific mention of the necessary proficiencies to apply them.

The aim of this research was to provide a holistic understanding of how the role of design is influenced by changes in business-making for a climate change. The objectives were to identify *a) How is the role of design changing with sustainable business strategies when compared to business-as-usual*, and *b) Which are the design competences required to effectively perform within sustainable business models?* Selecting case studies from manufacturing firms permitted a comparison of design targets before and after implementing a circular business model. It must be mentioned that this choice may have resulted in neglecting result-based services, as manufacturing firms still tend to develop services based around products (Roy, 2000; Tukker, 2013).

5.1. How is the Role of Design Changing with Sustainable Business Strategies?

Design was found to be evolving differently across case studies. ***Figure 2*** compares the sustainable business models analysed herein to BAU in product-based industries (see Generic production for sales model). CE business model archetypes were mapped according to whether *material efficiency* (e.g. reducing CO2 emissions and waste in their PLC) was more relevant to their strategy than *material sufficiency* (e.g. limiting material outputs and employing intangibles to fulfil a need). In this research, the evidently varied combinations of tangible and intangible value across CE business models proved to play an important part in determining the nature of design contributions.

Observed in the Y axis of ***Figure 2***, if the strategy is geared towards material sufficiency, the level of tangible value is reduced, which means the services gain importance to render customer value and to profit. Contrastingly, if the enterprise further seeks material efficiency, the tangible products continue to be central to deliver valuable offerings. This also impacts in the PLC stages that become crucial for streamlining value. Shown in the X axis of ***Figure 2***, resource extraction, manufacturing and sales are key stages for traditional product-based businesses. In contrast, sustainable business models have varied challenges, mostly aiming to generate further value during use, maintenance and EOL.

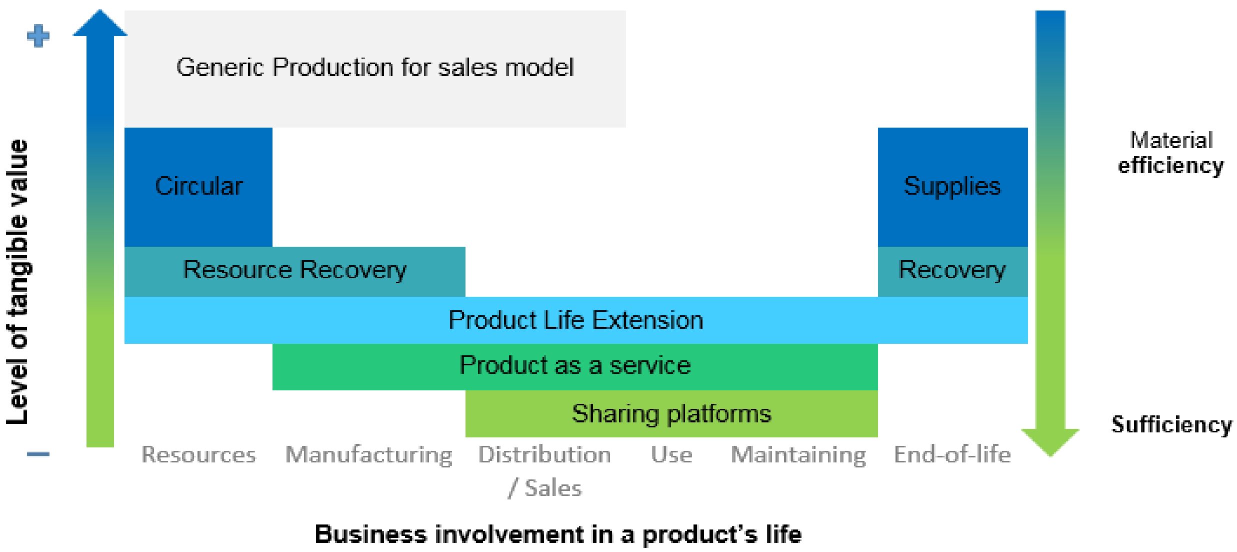

Figure 2: Circular Economy business models compared to business-as-usual.

Analysis of the different contexts studied demonstrated that some industrial transformations involve a barely noticeable change in the role of design, with their supply chain and operations facing the greatest challenge; while others represent increasing technical challenges for designers or extended responsibilities. Relevant changes were identified in the design process and product canvas.

5.1.1. The design process and product canvas

Aside from performing a primary function, designers must ensure that products are suitable for multiple lifecycles and continue to appeal to potential consumers. The use of standardised components as 'building blocks', or using a feedstock of available cores to create new products, is significantly more constrained than designing on a blank canvas, guided by a group of requirements. This represents a most interesting challenge for design innovation.

Product life extension appears to signify a reduction in the frequency of physical product design, which may allow for longer lead times, ensuring new products are thoroughly planned for superior environmental performance. Changes in the product system imply that different means, sometimes extrinsic to product embodiment, must be used by designers to create value. This scenario makes more relevant the suggestions of authors like Pettersen (2015), and Atwal and Williams (2009) underlining the need to embed symbolic and meaningful ingredients in products, as a way to enthuse users and create superior use and service experience.

Go et al. (2015) encouraged designers to become conscious of the range of materials they use to facilitate end-of-life separation. According to this study, however, implementing design methods for material recovery conveys only a small shift in the design process. In this aspect, there is still space for further contributions, as suggested by Reay et al. (2011), and designers are expected to take a more active part in driving scientific innovation.

5.2. Design competences required to effectively perform within sustainable business models.

Charnley et al. (2011) pointed out the need for a balance between design-specific knowledge and transdisciplinary skills, as crucial to engage in problem solving using a wider perspective for circular economy practices. The ten capabilities listed in ***Table 12*** were found to be key learning goals for designers to support the transformation of industry for climate change.

The decision to make a segmentation of the skills identified in this research, was largely informed from the study conducted by Kannengiesser and Gero (2015), who compared the design process of different disciplines (engineering, software and service design), finding a common ground in the cognitive process, yet commonalities reduced as the focus shifted to possible design solutions.

Based on this, it is believed that designers with different skills may attack the same problem but produce completely different solutions, according to an area of expertise. This study shows that depth of knowledge in some aspects of circular design is more relevant than others, depending on the business-market-technology scenarios. Therefore, employing distinct 'design personas' for different systems was considered an effective approach to optimise sustainable solutions. The design profiles in ***Table 13***, resulting from the present research, are proposed to fully cater to varied contexts of business models and product types within a closed loop industrial system.

The archetypes geared towards physical products, such as the *'Retrofitting designer'* and the *'Block building designer'* are evidently compatible with the widely spread literature concerning design strategies for component recovery and reuse. The profiles of the retrofitter and technical block builder answer to the demand, found on existing literature, to address the missing capabilities hampering the application in practice of available methods of DfRemanufacturing (Charter and Gray, 2008; Sundin et al., 2009; Go et al., 2015). This archetype is particularly important to support legislation aimed at repair, upgrade, re-use, disassembly and recycling of electrical and electronic equipment and other consumer goods such as the European Parliament and Council Directive 2012/19/EU(2012).

On the other hand, the design personas *'Product-service designer'* and '*Luxury UX designer'* hold the potential to successfully create better user experiences. Through an understanding of human practices and social behaviour, they would be equipped to meet customers' needs in business models that will employ resource 'sufficiency'. This approach involves further knowledge of service provision and the related operations that enable it.

The creation of 'biological cycles' through 'smart' materials that bring benefits to users and environment, have been encouraged by key authors (i.e. Benyus, 1997; Braungart and McDonough, 2002). Concept creation for such materials requires designers to be able to work with and understand scientists, something that is currently rare (Reay et al., 2011). As existing material assessment tools are only of aid with commodities, the *'Scientific designer'* is proposed with a set of capabilities that would permit them to collaborate in new material developments.

Finally, the *'Green fixer'* is suitable for more traditional approaches to resource circularity that do not imply a change in consumption patterns, and focus on reducing impact by substituting harmful elements of products and ensuring recyclability of materials. This particularly contributes towards legislation aimed at reducing the volume of packaging and packaging waste such as the European Parliament and Council Directive 94/62/EC (1994).

Undeniably, some capabilities that the '*Design personas*' represent can be found in existing careers. For instance, engineering design study programmes may provide the necessary depth of knowledge to generate standardised, reliable product architectures; but engineers also need to be thoroughly informed on reverse manufacturing techniques to be able to perform in a CE. Furthermore, recent studies on pathways to sustainable consumption demand further inclusion of user behaviour and psychological considerations (Rodriguez and Boks, 2005; Catulli, 2012), which, according to Pettersen (2015), technical disciplines are not currently equipped to do. Service engineering, as proposed by Sakao and Shimomura (2007), may be capable of effectively decoupling functions from material goods, but may be insufficient for design considerations concerning the 'product' element.

Comprehensive assessment of current design education programmes worldwide, and their ability to produce graduates that fit the design archetypes required for creating a circular economy in the manufacturing industry, must become a topic for future research. Circular design of the built environment, which was left out of scope, is also worth further exploration regarding skill-building.

5.3. Impact to audience

Changes in the role of design to cater to a changing industry, society and environment had been explored by a number of authors that contemplated the changing definitions of the discipline of design (Joore and Brezet, 2015) and offered a retrospective of its evolution up until the 21st century's circular economy (Andrews, 2015). Research concludes that designers should now be 'solution providers' and not only 'object creators' (Meroni, 2008; Roux, 2011).

This paper contributes to the existing body of knowledge by elaborating on the various ways in which product design and strategies are evolving. The methodology used enabled depiction of the different societal, systemic, business and technical aspects of the transformations that MNEs can undertake for climate change. Key insights were obtained regarding the impact that such transformations have in design strategies, and how a handful of new design capabilities have the potential to support existing policy surrounding the reduction of waste and increased utilisation of valuable assets. However, to achieve more holistic solutions for true circularity, changes in legislation are required that go beyond reduction and efficiency.

While qualitative studies are non-absolute (Eisenhardt, 1989), this multiple case study analysis offers the reader much needed insights on system transitions. The validation rationale of this research was consultative, where experts participated in verifying answers, rather than to providing answers. This afforded the researchers the potential to propose new answers based on empirical and theoretical data, while ensuring the correct interpretation of secondary data.

Incorporating a semi-structured interview in the methodology, to build the case studies, could have aided in obtaining first hand input and more case-specific details. However, the methods utilised proved an effective means to validate findings regarding necessary skill development.

Despite efforts to present a comprehensive set of case studies using data from multiple sources, findings cannot be completely objective, as is common to all case study research, and this remains a limitation of the research. A broader survey of industry may aid in refining skill sets and governance of design roles, as well as determining significance of demand for specific skills.

6. Conclusions

Holistic sustainability strategies imply a change in business making for MNEs, shifting focus towards dynamic, intelligent solutions. LCA and carbon footprint reduction tools have the potential to be valuable to inform decisions, but as tools, they require capable users to be effectively employed. Human capital skills are central to achieving resource optimisation, rather than solely relying on solutions provided by automation.

Design targets are changing due to the necessity to innovate while optimising resources, the emergence of new users in the PLC, and growing product embodiment constraints. The need for a variety of design skills to support closed loops has been made evident within this work; ranging from deeper knowledge of material science, engineering techniques and operational processes, through to proficiencies in service design and a deep knowledge of human behaviour. The need for a change in legislation to reflect this shift has also been outlined.

New designer archetypes, which are not exclusive to specific products or business models but to design roles, were modelled with skillsets to attend to the diverse requirements of the circular economy. Stakeholders in MNEs are encouraged to seek the development of such proficiencies in their product development teams to boost the successful execution of sustainability strategies.

Findings from this research provide a summarised but complete depiction of changes influencing design within CE systems, disseminates available knowledge on product strategies for climate change and further contributes to extend skill-building by identifying areas in which to focus design education. This has value for multiple audiences:

1. Local and multinational enterprises are provided with insight into the capabilities they need within their team to create products and services for successful sustainable business models.

2. Design practitioners are given guidance to identify areas to expand their skills.
3. Academics are provided a reference point to assess their syllabus, and ensure new generations of designers will be fully trained for future industrial needs.
4. Researchers are presented with a panorama to target investigations and technological development.

Illustrated by case studies, industries joining the circular economy can create greater value by employing designers and engineers to act at different stages of the value chain: from the development of renewable materials to enhancement of services. Yet the influence in practice of design must be extended by broader knowledge.

Above all, for any efforts to be significant, every actor involved in product creation –including consumers- must grasp the real impacts brought by almost a century of extract -make-dispose practices: The environmental and economic frailty in the global panorama signifies an end to the age of the 'consumer' as a depleting entity (Webster, 2015), and the beginning of the age of the 'user', as a pillar for restorative systems.

7. Acknowledgements

The authors would like to express their deep gratitude to the product development and sustainability managers who agreed to participate as validation panel, readily contributing to bring valuable inputs from a practical angle and robustness to the information contained in this study. Special thanks to the Mexican National Council of Science and Technology (CONACYT), for sponsoring the degree that led to this article.

Acknowledgements to the Ellen MacArthur Foundation, especially to Ken Webster, for their valuable work in driving forward the adoption of a CE, and creating databases and industrial networks that proved greatly useful for this research. Special thanks to Dr. Conny Bakker from Delft University of Technology, for setting foundations for this research, and providing expert feedback that greatly improved the manuscript. Special thanks also to Dr. Peter Joore, from the NHL University of Applied Science, for kindly assessing the correct use of the MDM methodology, and whose comments contributed to the quality of this paper.

8. References

Abdul-Rashid, S.H., Evans, S. and Longhurst P. 2008. "A comparison of four sustainable manufacturing strategies." *International Journal of Sustainable Engineering* (1:3), pp. 214-229.

Accenture. 2013. *Nokia evaluates alternative solutions to drive better management of electronic waste*. Accenture Executive Report. Accessed June, 2015. http://www.cas-us.com/SiteCollectionDocuments/ PDF/Accenture-Nokia-Evaluating-Alternative-Solutions.pdf

Alix, T. and Vallespir, B. 2010. "A Framework for Product-Service Design for Manufacturing Firms." *Advances in Production Management Systems: New Challenges, New Approaches.* IFIP Advances in Information and Communication Technology (338), pp. 644-651.

Allwood, J.M., Ashby, M.F., Gutowski, T. and Worrell, E. 2011. "Material Efficiency: A White Paper." *Resources, Conservation and Recycling* (55:3), pp. 362-381.

Andrews, D. 2015. "The Circular Economy, Design Thinking and Education for Sustainability." *Local Economy Sage Publications* (30:3), pp. 305-315.

Atwal, G. and Williams, A. 2009. "Luxury Brand marketing–the Experience is Everything!" *Journal of Brand Management* (16:5), pp. 338-346.

Audi (Audi Business Innovation GmbH). 2015. “Audi unite.” Accessed June, 2015. https://www.audiunite.com/se/service/en_unite.html

Audi AG. 2015(a). “Audi connect.” Accessed July, 2015. http://www.audi.com/content/com/brand/en/vorsprung_durch_technik/content/2014/03/connect.html

Audi AG. 2015(b). “Audi tron: Changes the world. Not everyday life.” Accessed June, 2015. http://www.audi.com/content/com/brand/en/vorsprung_durch_technik/content/2013/10/audi-tron.html

Audi AG. 2015(c). “The most important tools of Audi Design.” Accessed July, 2015. http://www.audi.com/com/brand/en/vorsprung_durch_technik/content/2013/10/audi-design.html

Ayres, R., and Kneese, A.. 1969. Production, Consumption and Externalities. American Economic Review, June

Bakker, C., Wang, F., Huisman, J. and den Hollander, M. 2014(a). "Products that Go Round: Exploring Product Life Extension through Design." *Journal of Cleaner Production* (69), pp. 10-16.

Bakker, C., den Hollander, M., van Hinte, E. and Zijlstra, Y. 2014(b). *Products that Last: Product Design for Circular Business Models*. First ed. Delft, Netherlands: TU Delft Library.

Benyus, J.M. 1997. *Biomimicry*. New York, N.Y.: William Morrow.

Bevilacqua, M., Ciarapica, F.E. and Giacchetta, G. 2008. "Design for Environment as a Tool for the Development of a Sustainable Supply Chain." *International Journal of Sustainable Engineering* (1:3), pp. 188-201.

Blizzard, J.L. and Klotz, L. E. 2012. "A Framework for Sustainable Whole Systems Design." Design Studies (33:5), pp. 456-479.

Boehm, M. and Thomas, O. 2013. "Looking Beyond the Rim of One's Teacup: A Multidisciplinary Literature Review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design." Journal of Cleaner Production (51), pp. 245-260.

Boulding, K. E. 1966. “The economics of the coming Spaceship Earth”. Environmental Quality in a Growing Economy: Essays from the Sixth RFF Forum. H. Jarrett. Baltimore, John Hopkins University Press: 3-14.

Bras, B. 2015. "Design for Remanufacturing Processes." *Mechanical Engineers' Handbook* II (1:10). Atlanta, Georgia: John Wiley & Sons, pp. 1-28.

Braungart, M. and McDonough, W. 2002. "Design for the Triple Top Line: New Tools for Sustainable Commerce." *Corporate Environmental Strategy* (9:3), pp. 251-258.

Canada, A., Mortensen, P. and Patnaik, D. 2007. "Design Strategies for Technology Adoption." *Design Management Review* (18:4), pp. 32-41.

Catulli, M. 2012. "What Uncertainty? Further Insight into Why Consumers might be Distrustful of Product Service Systems." *Journal of Manufacturing Technology Management* (23:6), pp. 780-793.

Charnley, F., Lemon, M. and Evans, S. 2011. "Exploring the Process of Whole System Design." *Design Studies* (32:2), pp. 156-179.

Crul, M., Clark, G., Kosoris, J. and Hong, L.N. 2009. "Design for Sustainability: Current Trends in Sustainable Product Design and Development." *Sustainability* (1:3), pp. 409-424.

Dobbs, R., Oppenheim, J. and Thompson, F. 2011. "A new era for commodities." *McKinsey Quarterly* (4), pp. 13-15.

Ecovative. 2015(a). “Mushroom® Packaging.” Accessed June, 2015. http://www.ecovativedesign.com/products-and-applications/packaging/

Ecovative. 2015(b). “Product design services.” Accessed June, 2015. http://www.ecovativedesign.com/products-and-applications/product-design/

Eisenhardt, K. 1989. “Building theories from case study research”. *Academy of management review* (14:4), pp. 532-550.

Ellen MacArthur Foundation. 2012. *Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition*. Isle of Wight, England: Ellen MacArthur Foundation.

Ellen MacArthur Foundation. 2013. *Towards the Circular Economy: Opportunities for the Consumer Goods sector*. Isle of Wight, England: Ellen MacArthur Foundation.

Ellen MacArthur Foundation. 2014. *Towards the Circular Economy: Accelerating the Scale-Up Across Global Supply Chains*. Isle of Wight, England: Ellen MacArthur Foundation.

Ellen MacArthur Foundation, 2015. *Circularity indicators: An approach to measuring circularity*. Isle of Wight, England: Ellen MacArthur Foundation.

Ellen MacArthur Foundation. 2015(a). “Circular economy network map: Ikea.” Accessed June, 2015. http://www.ellenmacarthurfoundation.org/uploads/gkm/page_508.html

Ellen MacArthur Foundation. 2015(b). “Circular economy network map: Steelcase Plc.” Accessed June, 2015. http://www.ellenmacarthurfoundation.org/uploads/gkm/page_490.html

Ellen MacArthur Foundation. 2015(c). “Ecovative.” Accessed June, 2015. http://www.ellenmacarthurfoundation.org/case_studies/ecovative

Ellen MacArthur Foundation. 2015(d). “Rype Office.” Accessed June, 2015. http://www.ellenmacarthurfoundation.org/case_studies/rype-office

Ellen MacArthur Foundation. 2015(e). “Splosh.” Accessed June, 2015. http://www.ellenmacarthurfoundation.org/case_studies/splosh

Giutini, R. and Gaudette, K. 2003. "Remanufacturing: The Next Great Opportunity for Boosting US Productivity." *Business Horizons* (46: 6), pp. 41-48.

Go, T.F., Wahab, D.A. and Hishamuddin, H. 2015. "Multiple Generation Life-Cycles for Product Sustainability: The Way Forward." *Journal of Cleaner Production* (95), pp. 16-29.

Hatcher, G.D., Ijomah, W. and Windmill, J.F.C. 2011. "Design for Remanufacture: A Literature Review and Future Research Needs." *Journal of Cleaner Production* (19:17), pp. 2004-2014.

Hertwich, E.G. 2005. "Life Cycle Approaches to Sustainable Consumption: A Critical Review." *Environmental Science & Technology* (39:13), pp. 4673-4684.

Holt, R., and Barnes, C. 2010. "Towards an Integrated Approach to Design for X: An Agenda for Decision-Based DFX Research." *Research in Engineering Design* (21:2), pp. 123-136.

Ikea. 2015. “Democratic design: Design for everyone”. Accessed June, 2015. http://www.ikea.com/ms/en_GB/about-the-ikea-group/democratic-design/index.html

Ilgin, M.A. and Gupta, S.M. 2010. "Environmentally Conscious Manufacturing and Product Recovery (ECMPRO): A Review of the State of the Art." *Journal of Environmental Management* (91:3), pp. 563-591.

Joore, P. and Brezet, H. 2015. "A Multilevel Design Model: The Mutual Relationship between Product-Service System Development and Societal Change Processes." *Journal of Cleaner Production* (97), pp. 92-105.

Kannengiesser, U., and Gero, S.J. 2015. "Is Designing Independent of Domain? Comparing Models of Engineering, Software and Service Design." *Research in Engineering Design* (26), pp. 253-275.

Kopnina, H. 2014. "Sustainability in Environmental Education: New Strategic Thinking." *Environment, Development and Sustainability* (17:5), pp. 987-1002.

Lacy, P., Keeble, J., McNamara, R., Rutqvist, J., Eckerle, K., Haglund, T., Buddemeier, P., Cui, M., Sharma, A., Cooper, A., Senior, T. and Pettersson, C. 2014. *Accenture Strategy: Innovative Business Models and*

Technologies to Create Value in a World without Limits to Growth. Accenture. Accessed May 23, 2015. https://www.accenture.com/cr-en/insight-circular-advantage-innovative-business-models-value-growth

Lovins, A.B., Lovins, L.H. and Hawken, P. 1999. "A Road Map for Natural Capitalism." *Harvard Business Review* (77), pp. 145-158.

Lozano, R. 2012. "Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives." *Journal of Cleaner Production* (25) pp. 14-26.

Madge, P. 1993. *"Design, Ecology, Technology: A Historiographical Review" Journal of Design History* (6:3), pp. 149-166.

MacDonald, E. F. and She, J. 2015. "Seven Cognitive Concepts for Successful Eco-Design." *Journal of Cleaner Production* (92), pp. 23-36.

McDonough, W., and Braungart, M. 2001. "The next industrial revolution." *Sustainable solutions: Developing products and services for the future*, edited by Charter, M. and Tischner, U. Sheffield, England: Greenleaf Publishing, pp. 139-150.

McDonough, W. and M. Braungart. 2002. *Cradle to Cradle: Rethinking the Way we make Things*. New York: North Point.

Meroni, A. 2008. "Strategic Design: Where are we now? Reflection around the Foundations of a Recent Discipline." *Strategic Design Research Journal* (1), pp. 31-28.

Nakajima, N. 2000. "A Vision of Industrial Ecology: State-of-the-Art Practices for a Circular and Service-Based Economy." *Bulletin of Science, Technology & Society* (20), pp. 54-69.

Nasr, N. and Thurston, M. 2006. "Remanufacturing: A Key Enabler to Sustainable Product Systems." *Proceedings of 13th CIRP International Conference on Life Cycle Engineering*, 31 May - 2 Jun 2006. Leuven, Belgium, pp. 15-18.

Ongondo, F., Williams, I. and Cherrett, T. 2011. "How are WEEE Doing? A Global Review of the Management of Electrical and Electronic Wastes." *Waste Management* (31:4), pp. 714-730.

Pettersen, I.N. 2015. "Fostering Absolute Reductions in Resource use: The Potential Role and Feasibility of Practice-Oriented Design." *Journal of Cleaner Production*. Published Online, February 2015.

Philips. 2014. *Rethinking the future: Our transition towards a circular economy*. Corporate press release, Koninklijke Philips N.V. 2014.

Philips (Koninklijke Philips N.V.). 2015. "Refurbished Systems." Accessed June, 2015. http://www.healthcare.philips.com/main/products/refurbished_systems/

Plant, A.V., Harrison, D.J., Griffiths, B.J. and Lam, B. 2010. "Design Standards for Product End-of-Life Processing." *International Journal of Sustainable Engineering* (3:3), pp. 159-169.

Rahimifard, S. and Clegg, A.J. 2008. "The role of the engineering community in sustainable development." *International Journal of Sustainable Engineering* (1), pp. 1-2.

Reay, S.D., McCool, J.P., and Withell, A. 2011. "Exploring the Feasibility of Cradle to Cradle Product Design: Perspectives from New Zealand Scientists." *Journal of Sustainable Development* (4:1), pp. 36-44.

Rodriguez, E. and Boks, C. 2005. "How design of products affects user behaviour and vice versa: the environmental implications." *Environmentally Conscious Design and Inverse Manufacturing, 2005.* Eco Design 2005 Fourth International Symposium IEEE. pp. 54-61.

Roux, C. 2011. "The New Meaning of Product Design?" *Design Management Review* (22:4), pp. 22-25.

Roy, R. 2000. "Sustainable Product-Service Systems." *Futures* (32:3), pp. 289-299.

Rype Office. 2015. "Lower cost quality office furniture." Accessed June, 2015. http://www.rypeoffice.com/

Sakao, T. and Shimomura, Y. 2007. "Service Engineering: A Novel Engineering Discipline for Producers to Increase Value Combining Service and Product." *Journal of Cleaner Production* (15:6), pp. 590-604.

Schenkel, M., Caniëls, C. J., Krikke, H. and van der Laan, E. 2015. "Understanding Value Creation in Closed Loop Supply Chains – Past Findings and Future Directions." *Journal of Manufacturing Systems*. Published Online, April 2015.

Senge, P., Lichtenstein, B., Kaeufer, K., Bradbury, H. and Carroll, J.S. 2007. "Collaborating for Systemic Change." *MIT Sloan Management Review* (48:2), pp. 44-53.

Simmonds, P. L. 1862. "Waste Products and Undeveloped Substances" London: R. Hardwicke

Splosh. 2015. "Why Splosh?" Accessed July, 2015. https://www.splosh.com/why-splosh/

Souza, G.C. 2013. "Closed-Loop Supply Chains: A Critical Review, and Future Research." *Decision Sciences* (44:1), pp. 7-38.

Stahel, W.R. 1997. "The Service Economy: 'Wealth without Resource Consumption'?" *Philosophical Transactions of the Royal Society of London: Mathematical, Physical and Engineering Sciences* (355:1728), pp. 1309-1319.

Stahel, W.R. 2013. "The Business Angle of a Circular Economy – Higher Competitiveness, Higher Resource Security and Material Efficiency." In *A New Dynamic: Effective Business in a Circular Economy*, edited by Ellen MacArthur Foundation. 1st ed. London, England: Ellen MacArthur Foundation.

Steelcase. 2015. "Sustainability: Products." Accessed July, 2015. http://www.steelcase.com/discover/steelcase/sustainability/

Sundin, E., M. Lindahl, and W. Ijomah. 2009. "Product Design for product/service Systems: Design Experiences from Swedish Industry." Journal of Manufacturing Technology Management (20:5), pp. 723-753.

Tukker, A. 2013. "Product Services for a Resource-Efficient and Circular Economy – a Review." *Journal of Cleaner Production* (97), pp. 76-91.

Van Nes, N. and Cramer, J. 2006. "Product Lifetime Optimization: A Challenging Strategy Towards More Sustainable Consumption Patterns." *Journal of Cleaner Production* (14:15), pp. 1307-1318.

Vasantha, G.V.A., Roy, R., Lelah, A. and Brissaud, D. 2012. "A Review of product–service Systems Design Methodologies." *Journal of Engineering Design* (23:9), pp. 635-659.

Vezzoli, C., Ceschin, F., Diehl, J. and Kohtala, C. 2015. "New Design Challenges to Widely Implement 'Sustainable Product-Service Systems'." *Journal of Cleaner Production* (97), pp. 1-12.

Webster, K. 2015. E-mail message to author, August 13, 2015.

Winkler, H. 2011. "Closed-Loop Production systems—A Sustainable Supply Chain Approach." *CIRP Journal of Manufacturing Science and Technology* (4:3), pp. 243-246.

Yin, R.K. 2009. *Case study research: design and methods*. Los Angeles, CA: Sage Publications

Zwolinski, P. and Brissaud, D. 2006. "Designing Products that are Never Discarded." In *Innovation in Life Cycle Engineering and Sustainable Development*, edited by Brissaud, D., S. Tichkiewitch, and P. Zwolinski, 225-244. Netherlands: Springer.