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Digital Technologies in Circular Economy Transition: Evidence from Case Studies

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ABSTRACT

Circular Economy (CE) is an economic system that closes material and energy loops in production and consumption systems. In this context, digital technologies (DT) are seen as solutions for Circular Economy implementation. However, while the use of digital technologies in industry is growing, their specific effect on Circular Economy is not widely explored. Hence, this paper aims to identify the roles of digital technologies supporting Circular Economy. Based on a literature review as well as three case studies, we proposed to evaluate the relationship between Circular Economy and digital technologies by using Business Model Canvas integrating the R-principles such as reuse, remanufacture and recycle.

1. Introduction

Circular Economy (CE) is mentioned in the literature as a strategy that opposes the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal (Homrich et al., 2018) and as an economic system that is based on business models, which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes (Kirchherr et al., 2017). Therefore, these R-principles also named as end-of-life strategies are seen as operationalization principles of CE (Reike et al., 2018). In this context, Digital Technologies (DTs) such as Internet of Things, Big Data Analytics and Artificial Intelligence are seen as the main supporters for CE transition because they are facilitating and initiating the implementation of end-of-life strategies (Bressanelli et al., 2018). Their contribution to CE is mainly explained with the knowledge that they provide on the condition, location and availability of the product that is circulating in different use cycles and production systems (Antikainen et al., 2018).

However, the relation between these subjects is not a widely explored research area (Bressanelli et al., 2018) due to the complexity of CE and novelty of research about DTs. In order to understand better the CE and DTs supporting CE, the objectives of the study are to conceptualize CE and identify DTs relevant to support CE, and finally to identify the roles and functionalities of DTs for CE transition. This paper conceptualizes CE with the explanation of its R-principles (reuse, remanufacture, recycle) and with Business Model Canvas schemas related to these principles by conducting a literature review. Finally, it investigates empirically the roles and functionalities of DTs for CE from three different case studies from secondary sources.

The next section presents the theoretical background of the study, and is followed by the explanation of the research methodology and the case studies. Results are mentioned in (section 4). The final sections are the discussion part and the conclusion.

2. Theoretical Background

2.1. Circular Economy and R-Principles

In practice, the implementation of CE in businesses is often characterized with hierarchically ranked end-of-life strategies called also R-principles such as reuse, remanufacture and recycle because they are seen as its operationalization principles (Reike et al., 2018, Ghisellini et al., 2016). However, the authors of CE literature have not widely focused on clearly defining and ordering this key concept of R-principles because in the literature, there are many different R frameworks and definitions ranging from 3Rs to 10Rs (Homrich et al., 2018). For example 3R refers to "reduce, reuse, recycle" which is accepted by Chinese scholars but it can also refer to other triple combinations such as "reuse, remanufacture, recycle" and "reduce, recovery, reuse" as identified by Reike

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Product-system	Resell/Reuse[3][7] Repair Remanufacture	Refurbish [3] Remanufacture [3]	Repurpose [3][7] Remanufacture
Component	Repair [3][7] Remanufacture [7] Reuse [6]	Remanufacture [7]	Repurpose [3][7]
Raw materials	Recycle [3][6][7]	Recycle	Recycle [3][6][7] Recover [3][7]
	Original function	Upgraded, original function	Different function

Figure 1. Classification of R principles (Potting et al., 2017).

Value creation Partners Activities Key resources	**Value proposition**	**Value delivery** Customer relations Channels Customer segments
Value capture Cost structure Revenue streams		

Figure 2. Business Model Canvas (adapted from Osterwalder and Pigneur (2010)).

et al. (2018). In order to clarify the definitions of R-principles, in Figure 1 we classified different Rs according to different layers and objectives. To be representative for each R, we choose a product-system, which contains multiple components and recyclable materials. In the vertical axis, there are different levels of a product-system and in the horizontal axis; there are different objectives of implementing R-principles. For example, when remanufacture is implemented at product-system level, at the end it is possible to stay with the original function of the product, upgrade this function, or create another function.

2.2. Business Model Canvas for Circular Economy

The move to CE is an example of a radical change, which will require a new way of thinking and doing business because the circularity essential of the CE changes the configurations of business models and supply chains, creates cooperative networks between different stakeholders and creates additional value propositions such as reuse, remanufacture and recycle, which will require the circular flows of resources (Bocken et al., 2016). These changes can be implemented by creating new business models based on these additional value propositions. In order to systematically design and test these new business model concepts or configurations, Business Model Canvas (BMC) can be used to provide an easy and collaborative way of defining the elements of a business model (Osterwalder and Pigneur, 2010). The illustration of BMC is in Figure 2 with the placement of its main elements.

As mentioned in section 2.1, each R-principle has its own definition and they are different in terms of their loop type (small, medium, long) (Reike et al., 2018). Therefore, they are different in terms of business model elements creating different Canvas schemas. In our approach, we choose to create three different Canvas schemas for reuse, remanufacture and recycle and then integrate them to obtain a global BMC for Circular Economy. Based on this Circular BMC, the value creation of CE mainly concerns the cooperation between different partners (Lewandowski, 2016) such as suppliers, logistics and recycling firms and the activities such as design for disassembly (Urbinati et al., 2017), reverse logistics and reprocessing of materials. In order to run these activities with the partners, we considered durable and intelligent products, digital technologies, recyclable materials and retrieved resources as the key resources of the value creation. In value proposition part, it is possible to offer remanufactured or recycled products and a use-oriented Product-Service System (Tukker, 2015) that supports reuse of the assets. These value propositions contain also positive impact on the environment (Bocken et al., 2018), increasing utilization of the asset (Bocken et al., 2014) and incentives for customers (Lewandowski, 2016) as some parts of the offer. The value delivery is mainly about the collaboration with the customers for the return and better use of products that can be reused, remanufactured or recycled. This relation requires a strong communication and take-back system between the manufacturers and the customers (Lewandowski, 2016). For the customer segments part, there are no specific segment. The customers can be owners or users of the products. However, it will be advantageous to find customers who accept these business models and who are responsible for the environment. Finally, in the value capture part there will be additional costs for recycling activities or maintenance services but it is possible to balance them with material & energy savings and value of retrieved resources from products collected back or from products that are used again (Lewandowski, 2016, Ellen MacArthur Foundation, 2016).

3. Research Methodology

The study was started with a literature review that contains three phases. Firstly, we searched articles about CE, secondly the articles about DTs and finally we crossed these two subjects by using keywords such as “CE and DT” and “CE and digitalisation”. For the third phase, we only identified eight articles from the literature of Web of Science and Science Direct focused exactly on this intersection. Therefore, we chose to explore the roles of DTs beneficial for CE by conducting an exploratory and inductive approach aimed to identify DT roles from case studies that are about these two research areas. The selected cases are mentioned in Table 1. The cases are selected according to following criteria:

1 The case should represent one of the R-principles (reuse, remanufacture, recycle).
2 It should be detailed in terms of use of different types of DTs.
3 It should be linked to more than one element of BMC.
4 Each case should represent different examples from different sectors.

Alpha is a household appliance retailer working in Northern Europe. Due to confidentiality issues, in the article they did not mention the real name of the company. The business model of the company is based on the reuse of household appliances by multiple users in different use cycles where they track the product with an IoT-kit.

Philips CityTouch model provides intelligent public lighting services to extend the use phase of streetlights, to remanufacture specific lighting components at the end of the first use cycle and to increase efficiency in public energy consumption for cities all around the world. They provide an IoT platform called lighting management platform and connect each lighting fixture to this platform with RFID (Radio Frequency Identification) network. The platform is used via web applications to manage streetlights and to analyse lighting data stored in the cloud.

ZenRobotics is a leader from Helsinki in waste sorting robots and proposes intelligent solutions for recycling activities by combining AI and Robotics. Their main objective is to achieve a high

Table 1
Selected Case Studies.

R-Principles	Case Companies	Sources	Mentioned DTs
REUSE	Alpha: household appliance	(Bressanelli et al., 2018)	IoT (Internet of Things) and Big Data Analytics (BDA)
REMANUFACTURE	Philips: lighting	(Ellen MacArthur Foundation, 2016)	IoT and RFIDCloud Computing
RECYCLE	ZenRobotics: waste industry	(Ellen MacArthur Foundation, 2019)	Artificial IntelligenceRobotics

Table 2
Relation between Circular BMC & DTs.

Cases	Roles	Canvas	Functionalities (Cases)	Digital technology
Alpha	Enabler	Value creation, delivery	Monitoring product location, condition, availability	IoT
			Predictive preventive maintenance	IoT & BDA
			Optimizing energy consumption	IoT & BDA
	Trigger	Value creation, proposition, capture	Monitoring product	IoT
			Creating the intelligent product	IoT
Philips	Enabler	Value creation, proposition, delivery, capture	Monitoring product	IoT
			Optimizing remanufacturing, energy consumption	IoT & BDA
			Virtual communication	IoT & Cloud
	Trigger	Value creation	Creating intelligent product	IoT
ZenRobotics	Enabler	Value creation, proposition, capture	Optimizing recycling	AI

rate of recyclables recovery from waste and to improve performance and efficiency of waste sorting. In this technology, waste is monitored by cameras and sensors and the visual data is send to the AI software called ZenBrain that analyses real-time data of the waste stream. Then, the heavy-duty robots make autonomous decisions based on this analysis. They decide which components or materials to pick in order to enter them to the recycling phase.

4. Results – Case Analysis

In this part, we use Circular BMC as a unit of analysis and we identify roles of DTs from the relation of this BMC elements and DTs used in each case.

Alpha Case:

In this business model, DTs such as IoT and Big Data act such an *enabler*. As IoT provides knowledge on the location and condition of the product, it becomes easier to create cooperative networks with logistics and technical support partners for the value creation. It also facilitates value creation activities such as repair and maintenance services with predictive and preventive maintenance. For the value delivery part of BMC (customer relations, channels and segments), the *enabler* role is more about IoT because it monitors user's activity on the appliance, so it prevents careless usage of the appliance and leads to a healthy and long-term relationship between Alpha and the user.

Another role of DT that we can observe in this case is the *trigger* role. Especially, IoT creates the value proposed by PSS, the key resource of this model "intelligent product" and the revenue streams. In order to generate value from the use-oriented PSS, it is necessary to track and monitor the condition, location and availability of the product and this monitoring activity becomes possible with the product equipped by the IoT sensors. Alpha monitors and tracks its products in order to move them between different users and to calculate their revenue based on the monitored use.

Philips CityTouch case:

The IoT network created by intelligent lightings facilitates the cooperation between the partners of this business model such as city authorities and Philips because they are able to manage lighting remotely on the cloud-based platform. These intelligent assets are *enablers* for Philips to offer remanufactured products and not to lose the value embedded in the used city lightings. In this case, they benefit from the virtualization for communication because Philips, city authorities and the intelligent lightings can communicate via lighting management software. As all the lightings are connected to the platform, Philips can maintain the system, authorities can control the system and lightings are acting such as an intelligent object that can communicate with them. Thus, with this control mechanism, the stakeholders can save energy and material by optimizing energy consumption of the lightings and generate more revenue from the retrieved value of remanufactured resources.

ZenRobotics case:

In this intelligent solution, AI algorithms act as an *enabler* of the main activity of recycling: waste sorting and reprocessing of materials. In order to achieve a high rate of pure secondary materials, the first step to do is to separate the waste accurately for the right recycling process. In addition, as the waste robots can be trained and the interface for the AI software is very user-friendly, this technology suits to different industries and to different waste types. Therefore, it can be a suitable solution for enterprises seeking to create partnerships with recycling firms using this kind of intelligent solution. Furthermore, with the use of AI, it becomes easier to use retrieved resources to offer recycled products and to create positive impact for the environment. ZenRobotics defends that this is the least expensive and the most efficient solution for separating waste that is why additional costs for sorting and reprocessing can be balanced with material savings and value of retrieved materials.

5. Discussion

Based on case studies, two main roles of digital technologies are identified as enabler and trigger (Nambisan, 2013:

1) Digital technologies as enabler: how digital technologies can facilitate the development of CE and improve the collaborations between actors of its ecosystem?
2) Digital technologies as trigger: how digital technologies can initiate or lead to innovation processes or outcomes or associated organizational routines and mechanisms?

By case studies, we find that the main functionalities supporting these roles are data collection, data exchange, data storage and data analysis, so they exist in each case study. However, the difference is made by the data analysis part that we can evaluate more deeply. With the case findings, we identified data analysis functionalities as Monitoring product location, condition & availability;

Predictive & preventive maintenance; Identifying remanufacturing opportunities; Optimizing product's energy consumption, recycling, remanufacturing, product design, pricing; Creating the intelligent product and Virtual communication.

The relations between the DT roles and functionalities behind these roles and BMC elements are summarized in Table 2 for each case.

6. Conclusion

This study is about the intersection of two research topics: Circular Economy (CE) and Digital Technologies (DTs). While the use of DTs is growing in many industries, their contribution to CE is not a widely explored research area. Therefore, this paper answers the questions of "What are the key roles of DTs supporting CE development? How are DTs supporting CE?" Taking into account the research questions, after a literature review conceptualizing CE, the study identified two main roles (enabler & trigger) of DTs based on three case studies representing different business models of CE. Furthermore, in order to answer the "how" question about the roles, the functionalities behind these roles and their relation with different Business Model Canvas (BMC) elements were explored. This paper is the first one to explore DT roles for CE by using a business model logic. The relation of DT functionalities with the Circular Business Model Canvas is not a research done before.

Based on the findings, the enabler role is more dominant than the trigger role. The trigger role only exists in the value proposition by offering a use-oriented PSS, exists in key resources by creating intelligent products and in revenue streams by making the pay per use logic possible. It means that this role is about the reuse option and it initiates some elements of this business model type. The functionalities behind this role are data collection, exchange, and storage and data analysis. The detailed functionalities about data analysis are monitoring product and creating intelligent product according to case findings and they are linked to Internet of Things.

However, the enabler role facilitates eight building blocks of BMC such as partners, activities, key resources; value proposition; customer relations, channels, and cost structure and revenue streams.

This study answered a research gap between CE and DTs but further research is required to validate the study findings, which are based on case studies from secondary sources. The future work could be a survey with the managers of the companies mentioned in the case studies. In this paper, application areas of DTs in CE are identified as household appliance, lighting, waste industries. The future research could explore another industrial sector to generalize the study findings.

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