Designing a Conceptual Framework for Industry 4.0 Technologies to Enable Circular Economy Ecosystem

Muhammad Rahim Ejaz
University of Pecs, Hungary
rahim.ejaz@live.com

Dániel Hegedűs
University of Pecs, Hungary
hegedus.daniel@ktk.pte.hu

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The paper is aimed at developing an ecosystem that can be used within the domain of the circular economy on the foundation of Industry 4.0 technologies. The study emphasizes the importance of Industry 4.0 as a crucial element in the development of the circular economic ecosystem. The circular economic ecosystem is comprised of a business model, business strategies, and resources and capabilities supported by a circular economy framework. This study adopted literature review analysis and case studies as mythology to analyse and synthesize the latest trends and aspects developing within the framework of the circular economy. The major findings of this paper present a theoretical conceptual framework of a circular economic ecosystem that can be adopted at organizational level. The study also supplies a way forward for future studies in this research domain as there are several factors which are found but need to be explored.

Key Words: circular economy, industry 4.0, smart manufacturing, circular economy ecosystem
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Introduction

The swift strides in the development of world's economy have empowered organizations to produce more efficiently and in large quantity. This has allowed organizations to reduce the costs that led to the development of competition in the consumer market. Consumer markets have been the foundation of the global economy since the industrial revolution. This has brought economic, environmental, and social challenges for the present and future generations. To meet the consumer demand, companies aim to shorten product lifecycles. However, it is an essential

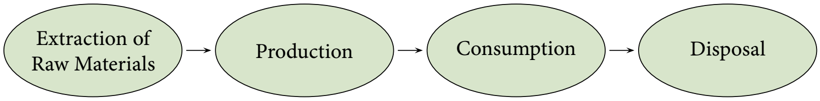

FIGURE 1 Linear Consumption Model (adapted from Bradley et al. (2018) and Kambanou and Sakao (2020))

consequence of this that the lifespan of products is constantly decreasing, thus encouraging re-purchase. This has led to the development of the so-called linear consumption model (Bradley et al. 2018; Kambanou and Sakao 2020).

This linear consumption model generates huge losses in both production and consumption (see figure 1).

The concept of a circular economy is wide and several aspects have been explored thus far. These include ecology, zero waste, clean production and closed loop. In the literature, several definitions of 'circular economy' can be found. However, this paper is specifically focused on circular economy, digital technologies integration and a circular business model. The phrase 'circular economy' first surfaced in the literature in the nineties and the initial concept was based on the idea of transition from linearity to circularity of economy. According to Momete (2020), literature is flooded with 'circular economy' after 2016, with an overlap of several discussion points among the concepts of circular economy, green economy, and sustainable production. The concept of a circular economy gained popularity after organizations started giving attention to greater sustainability. Bjørnbet et al. (2021) argue that the concept of a circular economy comes from the concept of closed-loop industrial ecology. Industrial ecology explains the industrial ecosystem which enhances consumption of materials to the optimal level and decreases waste to the minimal level. Rossi et al. (2020) also argue that the literature emphasizes that sustainability might drive organizations towards a circular economy, having innovation as an intermediary. Kazancoglu et al. (2021), Marjamaa and Mäkelä (2022), and Chauhan, Parida, and Dhir (2022) argue that the circular economy is an alternate socio-techno economic approach for a sustainable future. According to Luoma et al. (2022), the shift towards a circular economy is critical to reduce harmful environmental impacts. The aim in implementing a circular economy is to turn the linear consumption model *take-make-use-discard* into loops to extend product service lifecycle via reusing and recycling.

Guzzo, Rodrigues, and Mascarenhas (2021) have defined a circular economy as 'a set of advanced production and consumption systems that lead humanity towards sustainable development. It relies on the systematic implementation of strategies to reduce resource usage while enhancing value creation.' Bjørnbet et al. (2021) also define a circular economy as 'an industrial economy which is restorative by intention and design.' Hermann et al. (2022) have defined a circular economy as 'one that is regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption.'

The concept of circular economy needs more scientific research to form one standard definition but there is a clear linkage present between circular economy and sustainability. Hence our study develops the understanding that the concept of a circular economy eliminates the idea of 'end of life' and replaces it with 8RS: reduce, reuse, recover, recycle, remanufacture, refurbish, repurpose and redesign. The idea of transition requires a paradigm shift from the 'make, use, and dispose' concept to the idea of refurbishing, reusing, and recycling. A transition towards a circular economy can cause multiple complications within and outside organizations. However, these issues can be resolved by developing a circular business model and assessing it through simulations to make it error free before it is implemented in the real world.

According to Parida et al. (2019), the core objective of a circular economy is to reduce industrial waste by adopting reducing, reusing, and recycling strategies. According to Halonen, Majuri, and Lanz (2019), a circular business model should not be focused on how to reduce industrial waste as there is lots of literature available about this, but it should be focused on how to create customer value by offering products and services to the customers. This study aims to address this problem by offering a circular business model 'product-as-a-service' also known as a 'product service system' (PSS). According to Mastrogiacomo et al. (2021) and Li et al. (2022), PSS is defined as a combination of product and services to meet consumer needs through value. Li et al. (2021) argue that PSS backed by Industry 4.0 technologies is also called Smart PSS. The Industry 4.0 technologies provide a higher level of trackability of products and materials in the circulation and they also provide sufficient information about the product lifecycle. According to Bu et al. (2021), a smart PSS integrates products and services into a single-bundle solution. Products are networked through sensors to collect and transmit data to enable the manufacturer to provide value added services to the consumers. A smart PSS provides consumer satisfaction via product design modifications and extended product lifecycles. It helps to ensure the sustainable product lifecycle management.

This paper is divided into five sections. The second section is 'Literature Review;' here, the concept of a circular economic ecosystem is thoroughly discussed. The concepts of a circular business model, circular strategies, resources, and capabilities are also discussed in detail within the domain of a circular economic ecosystem. The third section is 'Circular Supply Chain of Business Model "Product-as-a-Service,"' where a circular supply chain is formulated which explains how this ecosystem will perform. A supply chain system is essential for the circular economic ecosystem. The fourth section is 'Theoretical Findings and Discussion;' here, a theoretical conceptual framework of a circular economic ecosystem is formulated which is based on our analysis of the literature review, and a discussion is undertaken about the findings. The last section is the 'Conclusion:' the study concludes with the idea that this paper provides a foundation for future studies in the field of circular economy and especially in the domain of the circular economic ecosystem.

Literature Review

Research articles have been selected from a wide research area to cover all the possible aspects of this paper. Sources such as Web of Science, Google Scholar, ScienceDirect and Scopus are used to gather research articles for this purpose. The research field of the circular economy is still a novel topic in the academic literature and yet more work must be done in this area of research. However, there is a lot of useful literature available which can be used as foundational pillars and guidelines for future studies. To the best of our knowledge, there is no conceptual framework available in the literature that can explain the circular economic ecosystem. We think it is a gap and we aim to formulate a conceptual framework to lay down a foundation for a circular economic ecosystem.

Industry 4.0 Technologies-Enabled Circular Economy Ecosystem

Over the recent years the term 'ecosystem' has become quite popular among the academicians. Kamalaldin et al. (2021) define an ecosystem as 'the configuration system of a multilateral set of players required to interact to materialize a focal value proposition.' An ecosystem is called a digital ecosystem when it is driven by the help of digital technologies; however, an ecosystem is called a circular economic ecosystem when it functions within the concept of a circular economy.

The role of Industry 4.0 in manufacturing organizations has been increasing drastically in the last few years. According to Sanchez, Exposito, and Aguilar (2020), there is a need for more advanced scientific studies to oversee transformation in the manufacturing industry so that it could be converted into smart manufacturing organizations. It will also help to answer core issues of digital transformation related to Industry 4.0 technologies. On the one hand, these advanced manufacturing technologies bring several challenges to an organization, such as integration among different departments, but on the other hand, these smart technologies also offer plenty of opportunities. According to Stornelli, Ozcan, and Simms (2021), these opportunities can help to improve the efficiency and productivity of a manufacturing organization. Factory floors can be transformed with the help of smart technologies like robotics and additive manufacturing to enable greater product customization and eventually to develop a digital ecosystem. Kamalaldin et al. (2021) argue that the core purpose of implementing digital technologies is to improve production efficacy and reduce costs and environmental impacts by augmenting operational and human capabilities. It can be done with the help of digital technologies like Artificial Intelligence (AI), Additive Manufacturing (AM), Internet of Things (IOT) and Big Data Analytics (BDA).

According to Parida et al. (2019), PSS is customer-centric and service-oriented in nature. For example, General Electric and Rolls-Royce sell their plane engines under performance-based service agreements to their customers. These agreements work on the 'power by the hour' principle and in this way, the manufacturer guarantees the performance of the engines in terms of reliability and availability of parts when needed. In another example, auto manufacturers in the UK sell their vehicles on lease under a mileage-per-year scheme to their customers. Customers pay reduced monthly payments if they agree to low mileage per year as per their lease agreement. It helps to increase the driving lifecycle of the vehicle and to reduce the residual value of the vehicle by reducing depreciation cost per year. Moreover, the vehicle will be protected by a full warranty by the manufacturer over the lease period.

The economy and society need further development, and sustainable value in a value chain seems to require manufacturing companies to move from the current 3R (Reduce, Reuse, Recycle) to the 8R approach (3R+ Recover, Remanufacture, Repurpose, Refurbish and Repair), where economic, environmental, and social aspects are considered. This closed system offers a solution to the increasingly severe shortage of raw materials by providing a new perspective. The circular economy business model sees each component as the raw material for the next product generation, thus reducing the amount of waste generated during production (Bradley et al. 2018; A. Jabbour et al. 2019).

The circular economy is a system of production where the goal is to keep products, components, raw materials, and energy in a circular flow to increase, recreate and maintain value in the long run. To achieve a circular economy, companies need to overcome several barriers and value chain actors also need greater collaboration (A. Jabbour et al. 2019). The transition to a circular economy business model has an impact on both a company's business processes and decision-making. The novel approach requires a change in both product development and supply chains.

CIRCULAR ECONOMY AND INDUSTRY 4.0 LINKAGE

According to Dwivedi et al. (2022), organizations are increasingly adopting Industry 4.0 and circular economy concepts in their business practices. Ciliberto et al. (2021) argue that several studies in the literature indicate a circular economy and Industry 4.0 as the future of organization. According to Romero et al. (2021), circular economy and Industry 4.0 are two different concepts; however, in recent years they have evolved together. Dantas et al. (2021) argue that Industry 4.0 supports the circular economy in achieving responsible production and consumption. A circular economy focuses on restorative industrial production while Industry 4.0 acts as an industrial engine in this whole ecosystem. Kazancoglu et al. (2021) argue that the circular economy and Industry 4.0 are the two sides of the same coin, to elaborate the relationship between them.

The transformation towards a circular economy goes along with the digital technologies. These technologies include big data, Internet of Things and cloud computing. They can help to upscale workers' skills performing circularity-based operational decisions. They also support inflating the product lifecycle through predictive maintenance that helps to create value and reduce waste for consumers. According to Chauhan, Parida, and Dhir (2022), digital technologies are summarized as big data analytics, Internet of Things, cybersecurity, cloud computing, augmented reality, integration and collaborative robots. A study conducted

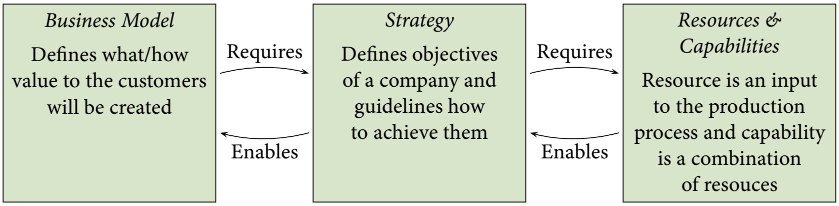

FIGURE 2 Circular Economy Framework (adapted from Halonen, Majuri, and Lanz (2019))

by Laskurain-Iturbe et al. (2021) shows that Industry 4.0 technologies have a positive influence on circular economy strategies. Another study conducted by Bag et al. (2021) shows a positive relationship between Industry 4.0 and circular economy capabilities.

Halonen, Majuri, and Lanz (2019) have developed a framework which can work with the circular economy. There are three main pillars of this framework, which are a circular economy business model, strategies, and capabilities. According to Halonen, Majuri, and Lanz (2019), their findings are too generic and there is a need to provide a framework which fits the circular economy criteria and its strategies. After an extensive literature review, a conceptual circular economy framework has been developed focusing on resources and capabilities. Resources like skills set and technology are the capabilities of an organization of doing something in a way in which others cannot. For example, manufacturing products at reduced cost while others struggle to compete; in other words, competitiveness.

In figure 2 it can be observed that first an organization needs to obtain or develop necessary resources and capabilities to develop strategies to formulate a business model that fits within the scope of a circular economy.

Circular Business Model

A systematic change is required to move towards a circular economy. Daou et al. (2020) argue that there are four fundamentals that need to be fulfilled to complete the transition process to a circular economy. These four fundamentals are *circular economy design, new business model, reverse cycles,* and *enablers.* This study focuses on only two fundamentals, new business model and enablers. C. Jabbour et al. (2019) also argue that implementation of a circular economy depends on a new business model and enablers. The concept of a circular economy is based on the three fundamental pillars of sustainability which are environmental, economic, and social. Rossi et al. (2020) believe that a circular business model is a form of a sustainable business model but this does not account for the three basic pillars of sustainability. They define a circular business model as 'the logic of how an organization creates, delivers and captures value within closed circuits.' A circular business model can also be defined as one that 'create[s], capture[s] and deliver[s] value to improve resource efficiency through innovation.' It can be a complicated task to define a circular business model as all the aspects have to be accounted for in the definition.

According to Ranta, Aarikka-Stenroos, and Väisänen (2021), there are two research paths to explore a business model in the context of a circular economy. One is traditional business model innovation and the other is sustainable business model innovation. The goal of a business model is to maximize the opportunities for an organization and eliminate threats. A circular business model is supposed to provide improvements based on circular economy principles. According to Centobelli et al. (2020) and Hina et al. (2022), a circular economy business model has three dimensions of value proposition. These are value creation, value transfer and value capture. Neligan et al. (2022) argue that value proposition can deliver performance by using PSS along with Industry 4.0 technologies. Industry 4.0 can be linked to RESOLVE strategies as it is vital for the achievement of PSS. Ranta, Aarikka-Stenroos, and Väisänen (2021), Brendzel-Skowera (2021), C. Jabbour et al. (2019), Lewandowski (2016), Neligan et al. (2022), Pizzi, Corbo, and Caputo (2021), and Wasserbaur, Sakao, and Milios (2022) have presented six different business model strategies known as RESOLVE. These strategies include *Regenerate* (set of activities for restoring and repairing the ecosystem), *Share* (sharing resources between the users by renting, reusing and sharing services), *Optimize* (inflation of efficiency of resources through modern technologies), *Loop* (keeping materials in a closed loop by promoting recycling, remanufacturing and return of used products), *Virtualize* (process of delivering value without materialising it in a tangible product), and *Exchange* (adoption of new and advanced technologies through exchange of old renewable materials for advanced materials). These strategies assist organizations to formulate their business model. According to Han, Heshmati, and Rashidghalam (2020), a product-as-a-service business model can also be called a lease model. Organizations adopt cost-cutting strategies by product leasing against a subscription fee. Kolling et al. (2022)

argue that in a product service system tangible ownership of the product is transferred to the consumer; however, a range of services are offered throughout the product lifecycle to augment functionality, durability and sustainability to create value for the consumers.

Li et al. (2021) argue that Industry 4.0 has brought the circular economy and PSS together since a circular economy system provides a competitive advantage to PSS, and PSS provides product lifecycle management for a circular economy system. Farsi and Erkoyuncu (2021), Li et al. (2022), Tukker (2004), Kolling et al. (2022), and Reim, Parida, and Örtqvist (2015) distinguish three levels of the product service system (PSS):

1. *Product-oriented PSS:* A provider, in addition to the sale of the product, also agrees to provide a range of services related to the product.
2. *Use-oriented PSS:* A provider does not transfer the tangible ownership of the product but provides it under a rental or lease agreement. For example, bike/car rental/leasing companies selling a range of services while maintaining the ownership of the product for the whole rental/leasing time.
3. *Result-oriented PSS:* A provider agrees to provide certain results and outcomes rather than providing the tangible product to the consumer. For example, cleaning services or laundry services, where specific results are promised by the provider and no physical product is delivered.

This study focuses on product-oriented PSS and two case studies are given in the next section. The importance of linking services and physical products is also emphasized by Dawar (2013), so that firms using related activities and services do not lose a competitive advantage. On the contrary, they even increase their competitive advantage as the number of their consumers increases. According to this approach, the competitive advantage available to the company lies not only in the activities conducted by the company but also in the activities which the company outsources.

How the Product Service System Works

According to Kolling et al. (2022), PSS incorporates services like installation, maintenance, repair, software/hardware updates, remote monitoring, consultation, training, financial services, parts availability, home delivery, documentation, customer support, warranty, inspection and diagnosis. After the end of useful life, services continue, such as return, reuse, recycle and remanufacture. Kolling et al. (2022) argue that several studies have concluded that PSS plays a vital role in a circular business model. In this business model, value creation can be enhanced by enhancing the product performance so that it exceeds customer expectations. Moreover, the additional services as maintenance can help to increase the product life cycle to a significant level. It will help to increase the length of flow of resources and subsequently increase the cycle for taking back the product for the purpose of reuse, recycle and remanufacture. Eventually, it will help organizations to develop and maintain long-term relationships with customers as well as suppliers.

Hyundai Blue Link – Case Study #1. Hyundai Motor Company has adopted this circular economy business model product-as-a-service, using one of the Industry 4.0 enabling technologies, the Internet of Things (IOT). With the help of IOT, Hyundai has managed to develop smart products which are continuously sending and analysing data in real time to improve customer experience not only with the product but also with the company in terms of after-sales services. Hyundai is providing a practical example of what Porter and Heppelmann (2015) have called smart connected products. Vehicles can send real time data of their operations to the manufacturer and receive software updates from manufacturers to avoid potential problems. In one example, in 2013, car batteries of a Tesla Model S caught fire when a metal object hit the car from the road. Tesla solved this issue by sending a software update so that cars could adjust their ground clearance according to the road conditions. In this way, products can continue to be in service for a longer period and customers will be able to establish long-term open-ended relations with the companies.

According to Porter and Heppelmann (2015), smart connected products need a completely new infrastructure to support this kind of business model. In our example, Hyundai did the same by establishing a completely new setup of remanufacturing and service stations. According to Han, Heshmati, and Rashidghalam (2020), they call it 'Blue Link.' In this model they let customers know that they have been provided with parts to reuse and with remanufactured parts after a recycling process. The customers with Hyundai Blue membership know that parts will be replaced when needed through a parts exchange system. It will help the company to reduce the use of natural resources for the purpose of manufacturing. The Blue Link Model is based on IOT. It starts when a customer buys a new or second-hand car and subscribes to the service. Car owners usually receive information about the condition of engine, tyres, and other parts over time. They also receive notifications about when to change the engine oil and other consumables. Customers can also notify the company through a mobile app for car problems and they can be directed to the nearest service centre.

Lim et al. (2012) provide a concept to visualize the working product service model which they have called a 'product service board' and which they demonstrate through case examples. This study has developed a conceptual product service board based on the already given example of the Hyundai Blue Link Model to illustrate how a product service system works.

This service model helps Hyundai to obtain all necessary information about their vehicles and customers can maintain their cars for a longer time. What we have learned for this Hyundai Blue Member Model is that cars connected through IOT and other smart technologies can help to solve issues in time and extend the product life. According to Porter and Heppelmann (2015), manufacturing has gone beyond the physical product. Technologies like smart phones can help customers to receive real-time updates about their products and augmented reality which helps manufacturers to solve critical issues and diagnose faults in the products in the minimum time. All the collected information from products remains in the cloud and is analysed by the manufacturer to produce a product with better functioning and performance.

HP Device as a Service (DaaS) – Case Study #2. HP DaaS helps to reduce the costs and complexity of device management with the help of IT tools. It provides a range of services which include device lifecycle management, repair services and AI-driven analytics for predictive maintenance and payment plans. It is a simple solution that optimizes resources. DaaS is a business model that improves end user productivity and reduces cost. According to Knerl (2021), DaaS is a concept which is not just about buying a product but is also about end-to-end services. For example, when a customer purchases a laptop under the DaaS business model, HP will grant full access to sales consultants and tech support from setup to compatible devices throughout the lifecycle of the laptop. It also provides discounts for different software purchases along with the payment plans.

This model helps customers to save time servicing the device as it is already taken care of by DaaS. Customers can access the latest software and

TABLE 1 A Conceptual Product Service System Board Based on Hyundai Blue Member Model

	Define	Locate	Prepare	Confirm	Execute	Monitor	Resolve	Modify	Conclude
Partners							Insurance company		
Dedicated Infrastructure	An online portal is available equipped with Big Data and IOT technologies	Parking area		An ERP system that updates customer and car information		ERP system relays car info to customers regarding maintenance	Integration of car repair stations with EPP		Monitoring and updating car status via technology
Services	Online system is in place for booking process and after sale services			Assistance in the car leasing process			Car maintenance services		
Product Condition	Specific car model is available	Displayed at the parking space		Car condition confirmed as described in the company's car history	Car is leased out to the customer	Car condition is observed	Car maintenance and repair is required	Car maintenance and repair is done	Car is back in service or returned
Customer Activities	Explore a car to get on lease	Go to the company authorized dealership	Prepare all necessary documents	Complete car purchase process	Drive	Observe for maintenance and potential breakdowns	Go to the dealership for periodic maintenance and in case of breakdowns	Get the service done	Renew or Return the car at the dealership when lease contract expires

NOTES Adapted from Lim et al. (2012).

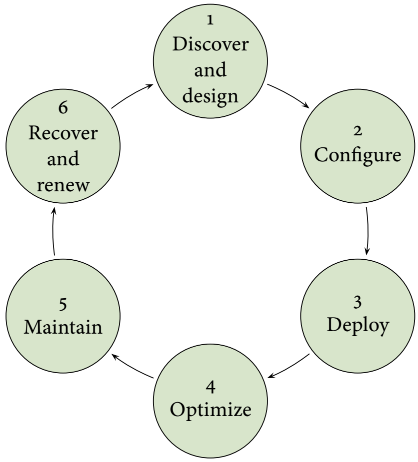

FIGURE 3
HP DaaS Business Model (End to End Lifecycle Services)

devices and DaaS can help them to upgrade their device with a suitable monthly subscription plan. DaaS collects data about product usage on a continuous basis and sends reports to the end user, which helps to reduce the operational cost of the device. DaaS also comes with an updated version of antivirus software, which helps to protect the device from any kind of virus attack. DaaS helps to save costs in terms of setup, maintenance, repair, and support services.

HP DaaS provides actionable reports about the product to maximize the user experience. The reports include information regarding battery life, hard drive, CPU utilization, security compliance and software usage. This information helps to diagnose any issues with the device so that they can be sorted out in a timely fashion. The portfolio of services is provided from the start to the end of the product life cycle.

The HP DaaS business model can be seen in figure 3. In this product lifecycle, the first step is *Discover and Design;* HP provides consultation services to discover and design the best-suited software package for your device. Data from the current environment is collected to make the best decision for the customer. Services include hardware compatibility testing, application testing, dashboard analysis and recommendations. The second step is *Configure;* a tailor-made IT package is recommended and configured by HP to save the time and energy of their customers. The third step is *Deploy;* devices, along with the configured IT package, are deployed to reduce time, risks, and costs. HP DaaS manages everything from logistics to complete installation of devices. The fourth step is *Opti-*

mize; HP DaaS optimizes the user experience by resolving device issues promptly through HP consultation services. The fifth step is *Maintain;* HP DaaS offers wide range of global services to the end users related to coverage, protection, and support to keep costs to the minimum and improve the user experience. The sixth step is *Recover and Renew;* HP DaaS helps to secure data and offers fresh technology packs and devices that support sustainability to increase end user experience. It is a secure method to retire or repurpose your old devices.

Circular Strategies

According to Blomsma et al. (2019), there are plenty of circular economy strategy frameworks available in the present literature. However, all these strategies only answer issues related to diverse types of structural waste and do not address the problems that can arise from the transformation to a circular economy perspective. It is beyond the scope of this study to provide a complete landscape of frameworks for circular economy strategies. There are four distinct levels at which these frameworks can operate. These are the *Macro level,* where a circular strategy framework is applied on the industry level as a whole; the *Meso level,* which involves certain industrial or business sectors where circular strategies can be applied; the *Micro level,* where circular strategy frameworks can be applied at an organization level; and the *Nano level,* where the circular strategy framework is applied at the product or product group level within an organization.

This paper focuses on the Micro level where the PSS business model embedded with circular strategies is applied on organizational level. Liu et al. (2021) argue that PSS creates value by providing services from the production to the disposal of the product. The supportive services include maintenance, monitoring in real time, fault diagnostics, parts and functions upgrades and in-time availability of parts, while disposal and conversion services include recycling, remanufacturing and other end of life services for the purpose of circulation. According to Salvador et al. (2021), finding the right strategies is the most important aspect for implementing circular economy principles successfully.

The study is inspired by the circular economy strategy framework developed by Potting et al. (2017). This framework of circular strategies has defined and explained in detail the circularity levels and applications of these strategies. Table 2 presents a list of eight circular strategies along with their definitions. However, the first column, which mentions circularity level and application, needs an explanation. These strategies

TABLE 2 Circular Economy Strategies

Circularity Level & Application	Strategy	Definition
Low Economical Usage of Materials & End of Product life Management	R1 Recycle	The processing of materials to obtain same or lower grade.
	R2 Recover	The incineration of materials by using energy to recover.
Medium Extension of Products & Parts Lifespan	R3 Remanufacture	Use of parts of an old/defunct product to build a new product with same functionality.
	R4 Repurpose	Use of parts of an old/defunct product to build a new product with a different functionality.
	R5 Refurbish	Restoration of an old product and bringing it to up to date.
High Smart Product Usage	R6 Repair	Maintenance of a defective product so that it can be used with its previous functionality.
	R7 Reuse	Usage of a product by another customer which is still in good condition and performs original functions fully.
	R8 Reduce	Usage by consuming fewer natural resources and materials.

NOTES Adapted from Potting et al. (2017).

have been placed into different levels of circularity based on the business model PSS. A smart product enabled with an Industry 4.0 technology allows customers to reduce the usage of the product which leads to less consumption of natural resources that are required to utilize the product such as electricity, gas, or petroleum products. In the literature, 'reduce' is also defined as a reduction in raw material usage by the manufacturer. However, this study particularly deals with the reduction of the product's usage, since there are several manufacturing models already available such as JIT, lean manufacturing, and smart manufacturing, which deal in reduction of raw material. Therefore, this study supports the narrative that if the usage of a product can be reduced then its lifespan can be increased, hence the product will be fit to use and reuse for a longer period.

This leads to the next strategy which is reuse. A product is only fit for reuse if the first user properly maintains it. It relates to the third strategy, repair, which also lies in the high circularity level. Only when a customer maintains and repairs the product in time, is it possible to reuse the product. Since products can be put to immediate reuse by following the strategies, that is why here the circularity level is high. The further a product moves back in the production line, the more the circularity level decreases. In the high circularity domain, the focus is on the smart usage of the product.

In the second domain of medium level circularity, the first strategy is refurbishing. When a product is old or damaged it is restored completely to make it look like a new product. On the other hand, if the product is too damaged to be restored then the manufacturer must repurpose or remanufacture a new product to serve a different or the same functionality, respectively. In this domain, the manufacturer must inject more resources to produce a new product from the defunct product, so here the level of circularity is medium. The third and last domain is the low level of circularity. Here, the manufacturer must use strategies like recycle and recover to manufacture a product from the initial phase of manufacturing. In this scenario, old and defunct products which are severely damaged are sent back to the raw material section of manufacturing where they are recycled to produce the same or lower grade materials.

Resources and Capabilities

According to Rovira et al. (2021), early signs of a digital economy were noticed in the US in the late nineties as the Internet started reshaping the traditional economy. This Internet usage brought high product quality as everything shifted online, from online shopping to online payments. That was the time when the customer service-oriented business model surfaced and gained popularity. In the 21st century, these digital transformations are playing a vital role in achieving competitive advantage. Business models and organizational structural designs must be in accordance with digitization. According to Rovira et al. (2021) the research indicates that big traditional companies can outperform digital start-ups if they incorporate digital technologies into their organizations.

An organization requires rethinking of its organizational structure when it decides to move from a product-centric business model to a service-centric business model. According to Ranta, Aarikka-Stenroos, and Väisänen (2021), digitization based on Industry 4.0 technologies can help organizations to implement circular economy business models. These technologies help companies to share data in real time so that products and materials can be tracked within the supply chain, which can bring value to the end user of the product. The digital technologies were originally believed to be beneficial in manufacturing alone but Ranta, Aarikka-Stenroos, and Väisänen (2021) argue that now it has been realized that the digital technologies not only help to track materials in the supply chain but also support the product-as-a-service business model by reducing the need for product ownership.

According to Antikainen, Uusitalo, and Reponen (2018), the product-as-a-service model is instrumental in digital transformation and the circular economy. The combination of technologies like Big Data, Data Analytics, Internet of Things, and other similar technologies provide an opportunity to create and capture value through the circular business model. Now modern technologies allow manufacturers to produce smart connected products that enable products to be remanufactured, refurbished, or recycled. Antikainen, Uusitalo, and Reponen (2018) argue that it is an accepted fact that digitization is imperative for implementing a circular economy. However, there are limited studies that explain how digitization functions as an enabler in the transition towards a circular economy. Ranta, Aarikka-Stenroos, and Väisänen (2021) have also identified gaps in the literature related to lack of empirical evidence of how digital technologies benefit the circular economy and the role of digital technologies in the circular economy.

Antikainen, Uusitalo, and Reponen (2018) argue that the product-as-a-service model is not a circular business model by definition but the enabling digital technologies help to achieve similar objectives as to the circular economy. The use of digital technologies helps to implement circular systems and reduce material use. Smart technologies not only help to estimate the quality of the product to enhance the product life cycle but also help in the supply chain by facilitating product life cycle management. Ranta, Aarikka-Stenroos, and Väisänen (2021) argue that digital technologies like the Internet of Things, additive manufacturing, cyber physical systems, and cloud computing can play an essential role in the transition towards a circular economy and the product-as-a-service business model.

The concept of the circular economy gained popularity among businesses and policy makers in the context of sustainability. Kristoffersen et al. (2020) argue that digital technologies are vital in order to implement circular economic strategies and to track down products and materials while they are in the supply chain system. Digital technologies like the

Internet of Things can help to monitor the process flow of products and materials, while Big Data can help to identify which materials are going into waste and which can be re-used as a raw material. It can also help to reduce production time and optimize maintenance and energy consumption. According to Kristoffersen et al. (2020), a survey shows that 70% of organizations have considered adopting a circular economy business model but only 12% of them have successfully implemented a circular economy with digital technologies. It means that, due to lack of knowledge and awareness, the true potential of digital technologies and the circular economy has not been explored.

Digital technologies, which are also known as Industry 4.0, are transforming various areas within manufacturing. However, digital technologies are still in the developing phase as they fail to provide fundamental support within the manufacturing sector. According to Kristoffersen et al. (2020), a research study shows that there are three main barriers in the implementation of a circular economy. These are no interface design, difficulty upgrading old technology, and outdated synergy models. All these barriers can be removed by applying digital technologies, such as networking, the Internet of Things, and automation, respectively.

Circular Supply Chain of the Business Model 'Product-as-a-Service'

Bal and Badurdeen (2020) propose to develop a system where consumers can place end-of-life products at collection points where, after sorting, these products can be returned to the manufacturing companies. Thanks to the development of info-communication technology, new types of products are appearing in the markets that are reshaping the processes within which companies have operated so far. These new products are transforming supply chains and forcing companies to change (Porter and Heppelmann 2015). Designing the right processes involves returning end-of-life products to companies and processing them. Processing includes determining whether the product can be resold immediately after redesign and refurbishment or if the returned end-of-life product cannot be redesigned, refurbished, and needs to be disassembled; any raw materials and components that can still be used need to be integrated into the next generation of products. In the case of products that are subsequently marketed after redesign and refurbishment, an important question is how consumers perceive these products. According to the research results, Porral and Mangin (2020) show that consumers have a positive image about product safety when buying recycled products, while environmental impacts and perceived quality do not play a role in decision making.

End-of-life products returned to companies are transforming the company's inventory management, as it is difficult to predict how many products will be returned or how many of them will be resold after redesign and refurbishment. The number of raw materials and parts to be incorporated into the next product generation is also difficult to predict. IOT and smart connected products can be a great help in solving these issues as they can provide continuous feedback to companies on consumer habits. Therefore, the role of production planning and control (PPC) in the circular economic model is important. This is due to changes in PPC, such as remanufacturing and refurbishment of the product. According to C. Jabbour et al. (2019), product return calculations are based on product quality, quantity, and production design.

Companies need to have the right infrastructure and processes in place to manage and store returned products as well as the right processes to dispose of raw materials and parts that are no longer usable. Product designers should therefore place particular emphasis on ensuring that the raw materials and components built into products can be used in as many product generations as possible. However, the next challenge concerns the inventory management and production planning department so that the circular economy allows raw materials and parts to come not only from suppliers, but also from the market through reverse logistics, such as the return of previously sold products (Dowlatshahi 2000; Sarkis, Helms, and Hervani 2010; Lembke 2002).

In the case of products that return to the company, it must be determined whether the product should be repaired or refurbished and then re-delivered to consumers. This can be economical for the company if the useful life period of the product has not yet expired and the cost of repair or refurbishment is recouped during the extended useful life period. If this is not economically viable, then the product must be disassembled and the extractable parts can be used in the next product generation. This disassembly and handling of raw materials and parts is an additional cost for the company, so it can be an effective solution only if the process is cheaper than producing new raw materials and parts.

This study developed a conceptual circular supply chain that can help to implement this business model. In this model we have explained how organizations can adopt a PSS business model in the context of a circular

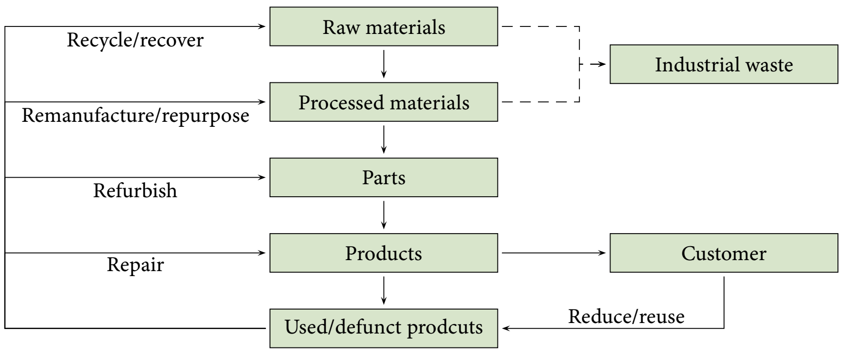

FIGURE 4 A Conceptual Circular Supply Chain of Business Model PSS

economy. It can be seen in figure 4 that organizations following a circular economy are taking back products from the customers and returning them to different sections, based on the condition of the product to perform functions like recycling, remanufacturing, redesigning, refurbishing, recovering, reducing, and reusing. However, if the parts are too damaged or worn out to be reprocessed or remanufactured, they can be sent to industrial waste site to be dumped.

Theoretical Findings and Discussion

The theoretical results in this study have been extracted from the extensive analysis of the present literature. The paper has developed a conceptual theoretical framework of a circular economic ecosystem which can be seen in figure 5. As this study is primarily focused on the circular economic business model based on Industry 4.0 technologies at the organizational level, these are the areas explored.

It can also be seen in figure 5 that the circular economic ecosystem is based on three foundational pillars. The first foundation is a business model which is PSS; its characteristics are also highlighted. The second foundation is strategy. Strategies can be devised as several levels but this study is focused on the micro level only and this level is further explored accordingly. We formulated R strategies which are further categorized based on their circularity level. The third foundation is resources and capabilities. They are also explored and this study believes that all resources and capabilities are essential for any organization's success. However, only Industry 4.0 technologies are further elaborated since these are the primary concern in this paper.

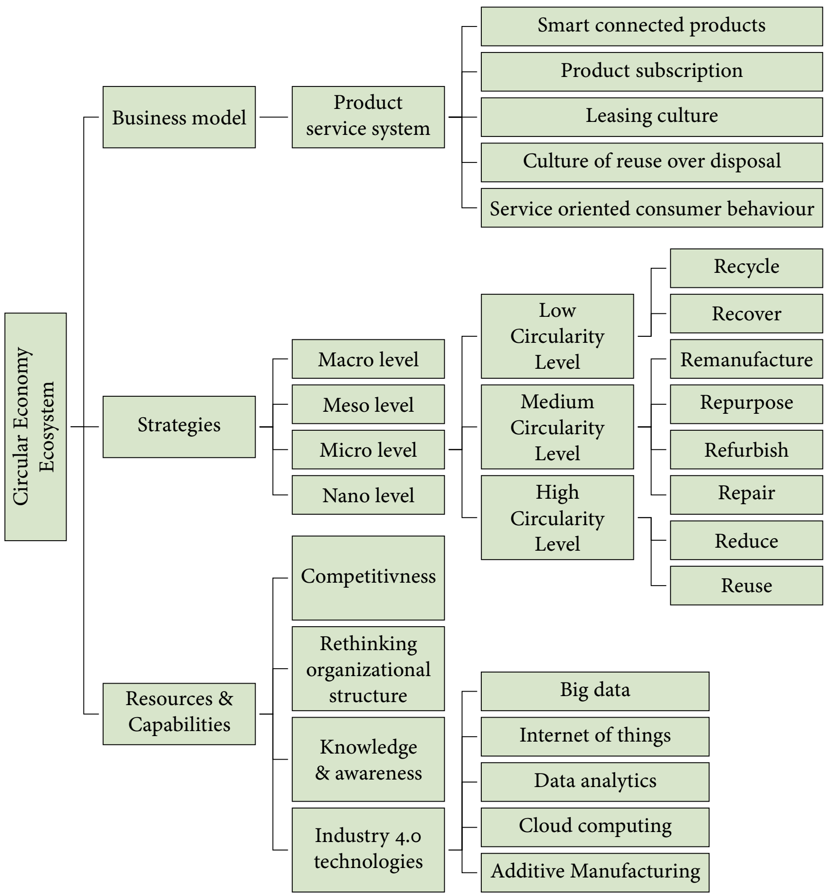

FIGURE 5 Industry 4.0 Technologies-Enabled Circular Economy Ecosystem Framework

RESOLVE strategies can only be achieved by applying PSS along with modern technologies. This study presents a framework for a circular economy business model that is successful and sustainable for organizations. Organizations should implement PSS backed by Industry 4.0 based on RESOLVE strategies. The study identified two gaps, which are lack of a circular economy ecosystem and lack of empirical evidence. This paper provides a theoretical circular economic ecosystem to fill this gap.

However, this study does not provide empirical evidence but has presented two case studies to support the argument that PSS is the most suitable business model for a circular economy ecosystem.

Conclusion

This paper is aimed at exploring a new dimension of production economics in the domain of the circular economy. This study has extensively analysed the literature to explain the traditional business model and problems linked to it. The study also examines the historical evolution of the circular economy as it was first introduced as reverse logistics in the academic literature. The concept of the circular economy brings sustainability when it is implemented through Industry 4.0 enabled digital technologies. These technologies help to increase production efficiency by reducing costs. Digital technologies can help to create a digital ecosystem which can help to form an ecosystem based on the circular economy and enabled through digital technologies. After the literature review, this study also discussed in detail that there are three basic business models that are suitable for the circular economy, but this paper chooses 'product-as-a-service' as it is best suited for the implementation of R strategies which are circular economy strategies.

The extensive analysis of literature reveals that the circular economy and Industry 4.0 are both associated with sustainability. This paper formulates its theoretical findings by devising a theoretical framework to connect the circular economy and Industry 4.0. In this framework a business model 'product-as-a-service' based on circular strategies which are implemented through Industry 4.0 technologies. A product service system is explained in the paper to help the reader understand how it works. A total of 8RS are given along with their circularity level. These strategies are being implemented with the help of digital technologies, as the literature emphasizes that digital technologies can help an organization to outperform against its rivals.

This paper also has its own practical implications related to the implementation of circular strategies along with the business model. The product-as-a-service model adopted by Hyundai Motor Company is successful; however, it requires a paradigm shift in the organizational philosophy. The importance of the circular supply chain is that it allows us to get possession of the product which is used as a service by the customer. With the help of smart technologies, the manufacturer can track the maintenance record and forecast future maintenance of the product as well. Product-as-a-service is a practical approach but it also requires a paradigm shift in consumer buying behaviour.

As far as managerial implications are concerned, related to the circular strategies and product-as-a-service business model, it is a managerial job to forecast the expected number of products returned to the manufacturer so that it can be determined how many products will be produced using R strategies and how many new products will be produced to meet customer demand. Then a production plan can be devised accordingly by the start of every production year. It will help organizations to manage and balance supply and demand issues.

A regulatory and legal framework is also required to protect consumer rights and ensure that the manufacturer provides all the services agreed upon to the consumer. It is the most important factor because if the manufacturer fails to provide a service, then the product service model will fail, too, and consumers will not subscribe to products-as-a-service. A regulatory framework will also force the manufacturer to follow R strategies and force consumers to use the product in compliance with R strategies.

There are a few limitations to this study, which includes lack of empirical data as few organizations follow the product-as-a-service model. In the future, researchers might be able to analyse empirical data based on manufacturers following product-as-a-service. This paper provides a sturdy foundation for further research in the domain of the circular economic ecosystem as there are opportunities to explore the circular business model, specifically product-as-a-service. The relationship between Industry 4.0 technologies and the circular economy is also a wide subject, hence new dimensions can be researched in this domain. Future researchers can also explore the economic viability and profitability of the product-as-a-service model in other industries.

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