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Industrial Symbiosis, Circular Economy and Industry 4.0 – A Case Study in Finland

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Abstract
The aim of our research is to gain understanding about material flow related information sharing in the circular economy value network in the form of industrial symbiosis. We need this understanding for facilitating new industrial symbiosis relationships and to support the optimization of operations. Circular economy has been promoted by politics and regulation by EU. In Finland, new circular economy strategy raises the facilitation of industrial symbiosis and data utilization as the key actions to improve sustainability and green growth. Companies stated that the practical problem is to get information on material availability. Digitalization is expected to boost material flows in circular economy by data, but what are the real challenges with circular material flows and what is the willingness of companies to develop co-operation? This paper seeks understanding on how Industry 4.0 is expected to improve the efficiency of waste or by-product flows and what are the expectations of companies. The research question is: How Industry 4.0 technologies and solutions can fix the gaps and discontinuities in the Industrial Symbiosis information flow? This research is conducted as a qualitative case study research with three cases, three types of material and eight companies. Interview data were collected in Finland between January and March 2021. Companies we interviewed mentioned use-cases for sensors and analytics to optimize the material flow but stated the investment cost compared to the value of information. To achieve sustainable circular material flows, the development needs to be done in the bigger picture, for the chain or network of actors, and the motivation and the added value must be found for each of them.

Keywords
Circular Economy, Industrial Symbiosis, Industry 4.0.

Introduction

The aim of our research is to gain an understanding of waste material or by-product-related information sharing in a circular economy value network in the form of industrial symbiosis, where one company's waste or by-product is used as an input by another company. This understanding is important when facilitating new industrial symbiosis relationships and utilizing digitalization to support the optimization of operations that are dependent on waste or by-product flows. Insight is needed from the point of view of companies working with waste material or by-products. For this reason, research data for this paper is collected from companies using different material flows and which are not representing a well-optimized industrial symbiosis.

The circular economy has been promoted by strategies and roadmaps, politics, and regulation. European Commission published the Circular Economy Action Plan in 2015 (European Commission, 2015) to boost the transition towards the circular economy, global competitiveness, sustainable economic growth, and new jobs. It covered the whole cycle from manufacturing to waste management, secondary raw material market and legislative proposals. The action plan targeted recycling and the re-use of materials. The action plan was completed in 2019. In 2020, European Commission adopted a new action plan for the circular economy, that aims at cleaner and competitive Europe. It includes sustainable product design and circularity in production as well as the value chains of key products: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and

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buildings, food, water, and nutrients (European Commission, 2020). European Commission aims to analyze how to measure the synergies of circular economy and climate change, to develop tools for modeling the benefits, and to promote circularity in national plans (European Commission, 2020). July 2021 European Commission published a new package of proposals for driving the green transition, including legislative proposals and new initiatives e.g. for carbon pricing, cleaner mobility, and renewable energy (European Commission, 2021).

In Finland, a new suggestion for circular economy strategy raises the facilitation of industrial symbiosis and data utilization as the key actions to improve sustainability and green growth (Finnish Government, 2021). Industrial symbiosis can be facilitated by the Finnish Industrial Symbiosis model (FISS). Funding opportunities are provided e.g. by the state grant for the development of circular economy ecosystems and knowledge platforms, by the Ministry of Economic Affairs and Employment of Finland.

When discussing with companies related to the circular economy and industrial symbiosis, the practical problem is to know when and how much material is available or supplied for production.

It is challenging when you use by-products from another industrial actor, you just cannot order the exact amount of material. No one produces by-products purposefully; it is a waste from production and naturally, everybody aims to minimize the amount of waste. In addition, the changes in production volume will change the amount of by-product.

Company A (Järvenpää et al., 2021)

Previous research shows that there is lack of information to find a suitable partner as well as the availability of waste and by-products (Antikainen et al., 2018; Bakajic & Parvi, 2018; Maqbool et al., 2018; Tura et al., 2019). Missing information is a central barrier for circular economy material flows and industrial symbiosis, as it is needed for efficient logistics, ensuring sufficient volumes, showing market demand and guarantee quality (Cramer, 2018). There is a gap in the knowledge of long-term industrial symbiosis at the point of view of data and information sharing in the value chain. Digitalization is expected to boost material flows in the circular economy by data, but what are the real challenges with circular material flows and what is the willingness of companies to develop co-operation by digitalization? This paper seeks understanding on how Industry 4.0 and digitalization are expected to improve the efficiency of waste or by-product flows and what are the expectations of companies. The research question is: *How Industry 4.0 technologies and solutions can fix the gaps and discontinuities in the Industrial Symbiosis information flow?*

This paper belongs to research that explores the role of information flows in smart industrial symbiosis. Other papers will answer the questions of how information flows in industrial symbiosis and what is the value of missing information.

Circular economy, industrial symbiosis and Industry 4.0

The idea of utilizing waste and by-products as input is not new. Frosch and Gallopoulos (1989) wrote over 30 years ago about the strategy for manufacturing where "wastes from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment". They wrote at the time that by the year 2030, there will be 10 billion people on the planet consuming critical natural resources and generating every year 400 billion tons of solid waste. They emphasized the importance of recycling, conservation, and alternative materials. Frosch and Gallopoulos (1989) introduced the idea of the industrial ecosystem, which is analogous to the biological one, with optimized resource consumption, minimized waste generation, and a connection of waste stream from one process as an input to another process. Today, these are central development topics highlighted by the European Commission and national strategies. According to the World Bank's publications, municipal solid waste was generated 2.01 billion tonnes in 2016. The expectation by 2030 is 2.59 billion tonnes and by 2050 3.4 billion tones (Kaza et al., 2018).

Circular economy

It is not only to connect waste or by-products as input to another process. It is about avoiding waste and loss of valuable resources. Ellen MacArthur Foundation defines that circular economy aims at designing out of waste and pollution, keeping products and materials in use, and regenerating natural systems. They divide the circular economy into two cycles: biological and technical. Biological cycles include materials that can be cycled back to the biosphere. The technical cycle consists of recovering and restoring materials by reusing, repairing, remanufacturing, and recycling (Ellen MacArthur Foundation, 2021; Ellen MacArthur Foundation, 2017).

Eurostat defines the aim of circular economy as to maintain the value of resources as long as possible by smart product design and smart production processes (Eurostat, 2021). Instead of finding a usage to the current waste or by-product, the whole industrial system and the products should be designed as there is no waste and the material circulates in the system and products have a long lifecycle.

Industrial symbiosis

There are several definitions for industrial symbiosis. Chertow (2007) defined in 2007 that industrial symbiosis must include at least three different entities that exchange at least two different resources and none of the entities is not primarily engaged in recycling. Lombardi & Laybourn (2012) defined in 2012 that industrial symbiosis "engages diverse organizations in a network to foster eco-innovation and long-term culture change". They stated that there are no requirements for geographic proximity.

Li (2018) defined in 2018 that industrial ecology aims to transform industrial systems into industrial ecosystems by mimicking biological ecosystems by closed-loop thinking, including material exchanges and energy cascading. According to Li, industrial symbiosis explores ways to facilitate synergy networks and support closed-loop thinking within and across industrial ecosystems, it requires a web of knowledge, a network of diverse organizations, the novel sourcing of inputs, the value-added destinations of non-product outputs, improved business, and technical processes, and a collective approach of a system as a whole (Li, 2018).

In our research, we define industrial symbiosis as an ongoing and long-term relationship between companies, where waste or by-product is utilized as an input to another process.

Industry 4.0

Industry 4.0 is a trending term with many definitions. Kumar et al. (2020) reviewed the term Industry 4.0, as there is no clear definition for the concept. Industry 4.0 is seen as an integration of digital technologies and real-time communication aiming to automate manufacturing systems. These technologies include e.g. smart sensors, IoT, big data and analytics, cloud computing, and machine learning. They define Industry 4.0 as a "generic term used for highly complex and automated manufacturing systems, services, and business processes where devices are aware of themselves, communicate among themselves and humans". As potential challenges to adopting Industry 4.0 Kumar et al. (2020) pointed out e.g. the need to develop and invest in technological infrastructure, management willingness, data security issues, need for standardization, lack of skilled staff, and potential jobs. Industrial symbiosis 4.0 would be driven by digital technologies and real-time communication.

McKinsey (2015) claims that companies lose data through information leakages that prevent the utilization of information in a value chain and cause inefficiencies. These inefficiencies are e.g. failures to understand customer needs or to transfer information, manually recorded data, and underutilized information. They suggest new value potential that could be achieved by eliminating inefficiencies by building an end-to-end information flow with the focus on optimizing the whole production network. McKinsey suggests recording only relevant data, transfer information in the value chain over the company borders and integrate data from different sources, identifying optimization opportunities by processing and synthesizing information as well as turning information into outcomes. In industrial symbiosis, information must flow between actors to enable the optimization of the whole co-operation network, but the question is how the relevant data will be achieved and turned into relevant information for partners.

Different terms come from different countries. Deloitte (2015) defines Industry 4.0 as "a further development stage in the organization and management of the entire value chain process involved in the manufacturing industry". The concept is used in Europe. Terms as the Internet of Things, Internet of Everything, and Industrial Internet are used in the US and English-speaking countries. The main characteristic of Industry 4.0 includes vertical networking of production systems, horizontal integration of global value chain networks, planning across the entire value chain, and acceleration enabled by exponential technologies. For industrial symbiosis, this means the communication within the factory and across factories and actors in the co-operation network.

PwC (2016) defines Industry 4.0 as Industrial Internet and Digital Factory. Industry 4.0 is driven by digitalization and the integration of the value chain, the digitalization of offering, and digital business models. Data and analytics are core capabilities. Industry 4.0 consists of digital technologies as IoT platforms, location detection, advanced human-machine interfaces, 3D printing, smart sensors, big data analytics and advanced algorithms, multilevel customer interaction and customer profiling, augmented reality, cloud computing, and mobile devices. For industrial symbiosis, this provides data collection and utilization for optimizing the operations as logistics.

It is obvious that information needs to be exchanged and understood in the same way in the network. Shared understanding can be created by using RAMI 4.0 reference model for digitalization. Digital models represent the physical world in the information world, Industrie 4.0 provides a framework of minimum requirements for the description including e.g. relevant parameters from the physical world, network structure and data format to exchange information (DIN, 2018). This kind of model for digital industrial symbiosis could provide the framework for collecting and sharing data in a smart industrial symbiosis cooperation network.

Sanghavi, Parikh & Raj (2019) lists some challenges that companies might face when implementing Industry 4.0 as to upgrading machines, errors in data processing, staff skills, cyber attack, lack of standards and benchmarked processes, and environmental impact caused by non-renewable energy sources. For this reason, the pilot actions and development must be done to learn and to find the best practices.

Schumacher & Sihn (2020) presented a model for industrial digitalization with maturity assessment. According to their research, there are two challenges regarding the implementation of Industry 4.0: a high level of abstraction and lack of guidance. Their model includes two stages, initialization, and implementation, as well as 11 tools. These tools include e.g. best practices, method collecting current activities from the company and assessing maturity, benchmarking service, a template to align digitalization projects, and KPI monitoring instructions. They state that the model enables strategic guidance for digitalization and provides a systematic approach for practitioners. This kind of guidance could be tested in the development activities and to produce knowledge for best practices.

Data on circular economy

Data don't automatically bring understanding. Xu, Cai & Liang (2015) talks about utilizing big data in industrial ecology saying that the research focus should be on utilizing data and new analytics tools for developing complex systems models and for characterizing consumption, purchase history, and modelling stock changes. Information sharing is important for successful industrial symbiosis and data visualization communicates the information for stakeholders. They expect that IoT enables tracking how energy and materials are used in real time. However, they remind better data do not necessarily provide better understanding. They state that there is much to do in transforming data into knowledge and action. Real-time tracking could be an important solution for industrial symbiosis and circular economy, that could enable efficient and timely operations.

Industrial symbiosis development activities should focus on exploring gains provided by data. Tseng et al. (2018) argue that there is a gap in operational data-driven solutions in industrial symbiosis, to enable sustainable solutions reducing used resources and emissions. They suggest sharing operational data within a supply chain network and empirical exploration on Industry 4.0 identifying sustainability gains as well as operational data-driven analyses for industrial symbiosis optimization. Okorie et al. (2017) reviewed data-driven approaches to the circular economy in manufacturing. They found "that the research that intersects circular approaches, digital technologies, and manufacturing data is still a new and developing area". They identified as sub- categories in the ICT research e.g. process automation, IoT and big data, the integration of processes and information flows. They found that research interest in this field is to find operational and digital solutions for the circular economy.

Organizations is recommended to publish non-sensitive data. Ruohomaa et al. (2018) argue that modern industrial symbiosis should be evaluated by data flows as well as by material and energy efficiency. Data enables strengthening the value chains and to open new possibilities. From the regional development point of view, they encourage organizations to publish non-sensitive data and to adapt Industrial 4.0 technologies. Understanding and learning by the data require quick pilot actions in the field lab environment.

The supply chain needs information that could be provided by digital technologies and there is a need to explore sustainability gains. Rajput & Prakash (2019) studied the connection of circular economy and Industry 4.0 in the supply chain, where they identified 26 enablers and 15 barriers. Industry 4.0 technologies enable the collection and to share real-time information on consumption and wastage. Identifying failures enables the optimization and control of the operational performance of the supply chain. Common barriers identified as interface design and automated synergy model. They suggest the empirical exploration of Industry 4.0 in gaining sustainability.

How to choose the relevant technologies to be empirically explored in the supply chain? Kerdlap et al. (2019) connect waste generators, collectors, and converters with IoT technologies aiming to facilitate data sharing. To support this aim, they introduced a framework to identify technologies to be utilized in the waste value chain.

How to involve consumers and customers to generate the needed data? Limba et al. (2020) argue that there is a need to develop data gathering and processing infrastructure for municipal waste management in order to increase its efficiency. One of the problems is the fact that it relates to the data collection and the sharing habits of consumers. They pointed out a question of how digitalization will impact waste management and is it already possible to utilize big data. In fact, there could be a lot of existing data, but the companies are not able to utilize it.

How to know, when products will reach the end of their lifecycle and will be returned? Mboli et al. (2020) proposed an IoT-based decision support system for tracking, monitoring, and analysing products in real-time. This model combines forward and reverse logistics enabled by IoT. Data gathered from products by IoT will give information about the forthcoming returned products.

Methodology and data

This research was conducted as a comparative and qualitative multiple case study. A qualitative case study was chosen to explore a phenomenon in depth and within its real-life context (Yin, 2018). Multiple case study was chosen to explore and compare the phenomenon with different waste material. The data collection method was semi structured interview, that provided the list of important themes to be covered. The research approach is inductive, as the aim is to understand the cases and to generate theory (Saunders et al., 2012). The time horizon in this study is cross-sectional, and it will provide a snapshot of events in a chosen time (Saunders et al., 2012).

This research consists of three cases that include three different waste material flows and eight companies, all located in Finland. Data were collected by interviewing CEOs or other relevant managers from each company. Interviews were conducted in Finland between January and March 2021, then transcribed and analysed. The aim of interviews was to gain the view of both, waste producer and waste user, to the waste material flow-related processes and information, the value of information, and the opportunities that companies see that digitalization can offer.

Data analysis included the identification of the challenges and the need related to information for each company, their view of how digitalization could solve the challenges, and are companies willing to utilize or develop new solutions. These descriptions are presented in the following section.

The cases were chosen to represent a different waste material flow to get an understanding how the value chain works from the point of view of information sharing. These material flows are biowaste, glass waste, and electrical & electronic waste. At first, the waste material using companies were chosen, secondly, their most relevant partners were chosen. Reflecting the different definitions of industrial symbiosis, all these three cases do not necessarily fit in the frame of industrial symbiosis as it purely way. However, these cases give insightful information on the issues that companies will face when using other companies' waste materials.

Case description is presented in Table 1. Company 1 in each case representsthe waste material user, company 2 and 3 represents the waste material producer or supplier. The material flows in cases are A) biowaste, B) glass waste and C) electrical and electronic waste.

Table 1
Case Description

Case	Companies		
	Company 1	Company 2	Company 3
A	Produce value products from biowaste	Food industry	Food industry
B	Produce products and recycled raw materials from waste glass	Supplier (collects from consumer & companies)	Supplier (collects from consumer & companies)
C	Produce recycled raw materials from electrical and electronic waste	Supplier (collects from consumer & companies)	

Results

This chapter describes the key challenges in waste material flow related information sharing between companies and what companies think of digitalization.

Material flow and the key challenge

The key challenge in each of these three cases in the point of view of the waste material users is to know how much material will be available and when i.e. how much material there will be to process for the following weeks. The key challenges are shown in Table 2.

Table 2
The key challenges

Case	The key challenge		
	Company 1	Company 2	Company 3
A	Material supply can increase rapidly without notification, challenges for logistics, and production. This might lead to the interruption of co-operation.	Production can increase rapidly, volume is high: fulfilment of containers interrupts production.	No challenges: volume and variation are relatively small.
B	Incoming volume and material availability are not known for the following two weeks.	There is no way to forecast the incoming volume.	No challenges: volume to be supplied is agreed by contract.
C	Incoming volume and the quality are not known for the following days and weeks.	No way to forecast incoming volume, it depends on the weather.	

Case A. In case A, the waste material user company A1 needs to know the production forecast from the food industry (companies A2 and A3) to plan its own production and transportation to pick up the waste materials. As biowaste goes bad and requires refrigeration, it cannot be stored for a long time. There is a certain capacity that can be processed during the week, so there is no reason to store extra waste material. The challenge in case A is the fact, that the biowaste from the food industry (companies A2 and A3) must be collected before the containers get full to avoid interruption in the food industry process. There must always be free capacity for biowaste. This comes problematic if production volume increases quickly, which can even double the production for the next week. This is particularly the problem between companies A1 and A2, and it is problematic for both companies and might lead even to the interruption of co-operation. Even the production estimates are shared regularly for a longer period, the quick updates often forget to be announced by company A2. If the production volume remains steady, as company A3, there are no issues with planning the transportation and production for company A1, it is enough to pick up once a week. Another problem relating to the waste user company A1 is the commitment for certain volumes towards their own customers.

Case B. In case B, the waste material user (company B1) needs to know about the glass waste supplier (company B2 and B3) the volume of incoming glass waste in real-time for the following two weeks in order to optimize the production capacity. In this case, it is possible to adjust the flow by warehousing. The quality-related information about incoming load would be beneficial to company B1. Another type of glass waste, plate glass, is collected straight from other companies, where real-time information from the container would enable the optimization of collection routes. Company B2 collects waste material from consumers and companies. There is no way to forecast the amount of incoming glass waste. Company B3 has automated collection points where consumers deliver the material and the volume of material supplied to company B1 is agreed by contract.

The waste user company do not have control over the incoming material flow. Instead, when the container gets full, it will be emptied at once: today there can be 10 lorries and tomorrow 0.

Company B2

Case C. In case C, electronic and electrical waste are collected from consumers and companies by company C2. The material flow is not steady, the variation relates to the season and the weather. Time-perspectives for volume information in the point of view of company C1 is within a year human resources and spare parts need to be estimated, within a month and a day unloading of the incoming lorries needs to be organized. Volumes are important information for the outgoing material flows as well, meaning selling to the customers of company C1. Waste collector company C2 finds that they have been able to estimate the amount of waste until the Covid-19 pandemic since the year 2019 the volume of waste material flow was increased. The waste material is collected at waste stations and in smaller collection points, where the consumers bring their devices. Waste flow is smaller during the winter and increases in springtime. Typically, over half of the yearly volume is collected between May and September, but how the volume divides into these months, depends on the weather. Company C1 has explored container monitoring with 0 lux cameras that see the filling rate in darkness. This provides an opportunity to optimize transportation routes and processing as well it prevents containers from getting full and it leads to a steadier material flow. They state that at the moment, the waste user company C1 has no control over the incoming material flow. Instead, when the container gets full, it will be emptied at once, today there can be 10 lorries and tomorrow 0.

The difficulty is the fact that the waste stations have no intention of utilizing IoT, instead, they consider that it is just a container and when it gets full, the transportation will be ordered

Company C2

What do companies think of digitalization to improve information sharing?

Some companies consider that real-time information would be the key to the development. Some companies do not see any monetary value for data collection and are not willing to develop because "it is just waste". Table 3 summarizes what companies think of the opportunities provided by digitalization.

Table 3
Thoughts of digitalization

Case	Thoughts of digitalization		
	Company 1	Company 2	Company 3
A	Do not see any monetary value for collecting data from processes.	Are not willing to invest too much in developing waste flow-related collaboration	Do not see any added value to monitoring the fulfilment of containers.
B	Digitalization is seen as the key to collecting material from the whole Finland.	Data is already utilized to optimize the emptying frequency. If data transfer would become very cheap, real-time information from containers would be possible	Automatization in the material collection already exists. Willingness to develop if an adequate repayment period exists.
C	Real-time monitoring of container transportation is important.	Is interested in big data to analyse and visualize the flow of customers and accumulated materials.	

Case A. Company A1 that uses biowaste, do not understand yet, what would be the benefits of the digitalization to improve material related information sharing with the biowaste producer companies A2 and A3. Company A1 does not see any monetary value for collecting data from processes and investing in data collection. Instead, A1 would prefer to get access to the information system of the food-producing company A2, to verify possible updates to the planned production volume. Company A1 states that it is enough to share information in a spreadsheet file anytime there have been updates compared with the investment costs of digital systems. The real-time information collected from the biowaste container does not satisfy company A1, as they need the information beforehand in order to have time to take action. Company A1 states that the active interaction between companies is the key to solving this challenge. Company A2 has a new ERP system, they are trying to minimize actions done by humans. They would prefer if the waste flows do not require any actions or work from them, the goal is that waste goes to the container and someone picks it up and there would not be a need to calculate or estimate anything nor select collaborators to receive waste. They are waiting for new bio production factories that they expect to boost the demand for biowaste that makes it possible to develop collaboration between companies, as further as both partners are satisfied. As company A2 production forecast might vary quickly, during a couple of hours the next week's production might be doubled, and the updated information is forgotten to share for company A1, the digitalization might be the key to sharing updates automatically. Company A2 states that the willingness to share information relates to the companionship between companies, in long-term collaboration, there is trust and willingness to share information openly. There is a need to evaluate the collaboration relationship to the future as well, there has to be trust that the partner is able to provide services needed in the future. There should be joint development and open discussion, on what are the desired directions in the future for collaborating companies. In this case, companies A1 and A2 have joint meetings twice a year. Company A2 is not willing to invest resources too much for developing understands, that if the waste receiving company A1 benefits from the joint development activities, company A2 might get monetary value as well. Company A3 states that even if a system exists for measuring a by-product and monitoring the weight and the fulfilment of containers, it would not provide any added value. waste flow-related collaboration.

We are not willing to invest resources too much for developing waste flow-related collaboration. It is just a by-product, not a product.

Company A2

Case B. Company B1 that uses glass waste, is building a roadmap including digitalization. They see that digitalization and automatization are the keys to collecting especially plate glass from the whole Finland with real-time information and by a small carbon footprint. To get the plate glass waste from small companies, real-time monitoring must be provided as a service. Company B2 has collection points for glass waste. They are trying to utilize the growing amount of data to optimize the emptying frequency automatically, instead of planned frequency. They think that if data transfer come very cheap, they could have a sensor in each container to measure the fulfilment level, but they state that it must be very cheap e.g. 1*e* per month per container. Company B2 suggests that the biggest information needs in circular economy and sustainable development are to support political decision-making to find solutions that really are sustainable. The problem is that the life-cycle analyses are case-specific, but it requires information on operative activities with different options. Company A2 states that information sharing might not be the problem, the problem is that there is no information, or it might be recorded or reported the wrong way. It relates a lot of human activities to measure, analyse and store data. Company B3 uses automatization in glass waste collection, and they are interested in digitalization and willing to develop if it has an adequate repayment period. Nevertheless, because of the large number of logistic partners who would probably make changes in their systems too, the development activities must be carefully considered. They have regular dialogue where they present development ideas and evaluate if the solution is viable for the 5-year time.

Case C. Company C1 says that their scale software will be changed, which affects the processing and management of information. They have tested remote monitoring to follow the transportation of containers in real-time. Because the information needs vary between stakeholders, it has to be possible to produce different information packages according to their needs. Company C2 would be interested in big data to analyse what customers bring to the collection stations and how they are moving in the area to estimate the volume of each type of collected materials. The size of the collection points depends on the location, optimizing the system requires information flows due to the fact that some points require emptying once a year, while another point each day. Company C2 sees the consumer behaviour in collection points and supposes that if large collection stations would be open on weekends, the biggest volume would be collected then. In this case, containers could be emptied at the beginning of the week that would give a predictivity according to the incoming transportations to company C1. Opening hours on weekends would probably require an automatic waste station. Especially in big cities, there would be a need for pick-up services that can be ordered e.g. by mobile application. Company C2 expects that unmanned or automatic waste stations would bring the development, since there will no longer be a human to give instructions, but the consumer will be guided via digital technology. Without proper guidance, consumers put everything together, that causes fire. Automated waste stations provide an opportunity for consumers to visit the waste station on weekends. It could be tested that would consumers bring their waste mostly on Saturday and Sunday. In this case, containers could be emptied at the beginning of the following week. This could be one way to balance the material flow. Company C2 sees that in large cities consumers would need a service to collect their electronic waste at home in case they do not own a car and there are no waste station or collection points nearby.

Comparison between cases

Comparison between cases is summarized in Table 4. All the waste using companies A1, B1 and C1 would benefit from the more accurate information on material availability, supply, or incoming transportation to plan the production and to sell their products to their customer.

Digitalization is seen differently in companies. Company A1 states that they do not need the real-time information collection but more accurate forecasts and especially the announcement of the updates. Company A2 prefers, that they would not have to give any forecasts or updates to waste receiving company. Companies B1 and B2 think that the real-time information would be beneficial in order to optimize logistics, for B1 this means providing services to plate glass waste producing companies. Company B2 is very interested to have measurements from containers, but they state that the data transferring fees must get lower (e.g. 1*e* per month per container) before this is an option for them. Company B3 already has automated collection systems and real-time information available.

Company C1 is interested in using remote monitoring to follow their containers in real-time. Company C2 is interested in observing and visualizing the flow of customers and the accumulation of waste materials in waste stations.

The aim of our research was to gain an understanding about information sharing between companies. According to the interviewed companies, there

Table 4
Comparison

Case	Comparison		
	Company 1	Company 2	Company 3
A	Do not need real-time information, but accurate forecasts and updates.	Do not prefer giving forecasts or updates.	No variation, no value to collect or share information.
B	Needs real-time information.	Is interested to develop real-time information collection.	Has already an automated system and real-time information available, but the information is not shared.
C	Needs real-time information	Is interested to predict by big data.	

is a need for better information on the material availability as well as a need to forecast availability. In most companies, there is no accurate data available for sharing. One company reported that data exists, but it is not shared. One company stated that they are not willing to collect and share any data, and they expect that the material receiving company should handle the highly variable volume without communication. Three companies were interested to collect and utilize real-time information, but they see challenges regarding the costs of the system compared with the added value. One company would probably benefit for the real-time information, but they prefer more accurate volume forecasts and updates.

The research question was How Industry 4.0 technologies and solutions can fix the gaps and discontinuities in the industrial symbiosis information flow? There are hight expectations in the literature that IoT, data and analytics would provide a solution for the efficient circular economy material flows and industrial symbiosis. As technology provides opportunities to connect waste producer with waste collector and waste user in real-time, information flow between actors could enable the optimization of the operations. In industrial symbiosis, this means the communication within and across companies in the network.

There is a need to develop and there are technologies available. However, the willingness to develop information sharing depends on the added value information brings compared with the investment cost. The added value may relate to the optimization of processes or higher profits from the waste material.

Discussion

How to succeed in boosting the required transition (European Commission, 2015; European Commission, 2020; Finnish Government, 2021), towards the circular economy and closed-loop material flows as the central challenge is lack of information on the material supply or availability (Antikainen et al., 2018; Bakajic & Parvi, 2018; Maqbool et al. 2018; Tura et al., 2019; Cramer, 2018)? Companies have different interests in development. To achieve sustainable circular material flows, it is obvious that the development needs to be done in the bigger picture, for the chain or network of actors. However, all companies are not interested to take the system view, they just want someone to handle the material without any exchange of information. For this reason, motivation for the development must be found for each actor in the network.

Industry 4.0 technologies are expected to enable sustainable circular material flows, and the most potential is seen in the literature on sensors, IoT and data analytics (Kumar et al., 2020; PwC, 2016). Companies in two of our cases B and C mentioned the benefits of sensors and analytics. Companies in case A were not interested in development with these technologies: company A1 stated that they do not need the real-time information from the container of company A2, but updated forecasts. However, company A1 would probably benefit to be notified if the speed of biowaste generation is increased to get some time to react. This would benefit company A2, which would prefer to organize biowaste operations so that they do not have to do anything to estimate or give updates for receiving company. Real-time monitoring with sensors and IoT combined with data analytics could provide valuable information for prediction, that give accuracy for the estimations for a longer period.

The added value that digitalization could give for circular material flows, requires evaluation in the network: which information should be generated for whom and what would be the value of information compared with the benefits and investment costs.

Limitations

It is obvious, that data gathered by interviews depends on the respondent: how much the person knows, how important the topic is in the company, and what kind of relationship they have with their partnering companies. Group interviews in case companies could give a broader view for the topic. However, a challenge in this kind of research among business partners is to obtain information that is exact enough and explains the real situation, due to the sensitive relations between companies.

As this research included three cases with different materials, we did not get deep insight into one material flow specific issue and thoughts of digitalization among several companies. Instead, we get an overview of different circular material flows and how digitalization could serve them all.

Further research

This paper is a part of research that goal is "smart industrial symbiosis". Analysis of the interview data will continue, and the forthcoming papers will cover the aspects of how information flows in the circular economy value chain and what is the value of information. More understanding would be needed for the forthcoming changes in the regulation and market to evaluate the opportunities and challenges utilizing sensors, IoT and analytics to optimize material flows.

Research could be extended to the whole chain or network: the waste producer (companies and consumers), the waste user, and the user of the end-product. The research could model the whole system from the point of view of material flow and related information. This kind of extension might not be easy to implement, due to the motivation of companies to join the research and "reveal" their business partners. However, the motivation could be found the sustainable development targets, that can be achieved by the optimization of the system.

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