Internet of Things and Cloud Computing Enabling Circular Economy

A tool rental service

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Abstract - **Internet of Things, cloud computing and big data analytics are technological innovations that have the power to transform traditional businesses. These technologies can enable and accelerate a circular economy with closed material loops on a broader scale. We aim at providing information on how to disrupt prevailing linear business models by employing digital data, cloud computing and Internet of Things technologies. We give the reader an overview on circular economy and most prominent digital technologies affecting the incumbents of industry. We present the current deployment of a tool rental service and develop a scenario anticipating the possible future of the tool rental service. The envisioned tool rental scenario provides understanding on the effects of digital technologies and helps companies in identifying more sustainable and circular business models.**

Keywords - circular economy; Internet of Things; cloud computing; tool rental service.

I. INTRODUCTION

This paper explores how Internet of Things (IoT) and cloud computing can advance circular economy business model [1]. The concept of a circular economy (CE) describes an economy with closed material loops. CE focuses on reusing materials, and creating added value in products through services and technology-enabled smart solutions. This implies that the concept of CE is a continuous development cycle that aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles [2]. If EU manufacturing sector would adopt a CE business model, net material costs savings could be worth up to 570 billion euros per year and growth opportunities 320 billion euros by 2025 [3]. The circular concept fosters also wealth and employment generation against the backdrop of resource constraints [4], [5]. This transformation from linear "take-make-dispose" economy to circular one requires disruptive innovation in business models and technologies.

IoT is a general term relating to the various technologies for connecting, monitoring and controlling devices such as sensors, home appliances, vehicles and industrial devices over a data network. We define IoT as a computing concept where internet-enabled physical objects (e.g., sensors, actuators, tags, smart machines) can network and communicate with each other to achieve greater value and services by exchanging data and producing new information [6]. IoT relies on the three pillars related to the ability of smart objects: i) *to be identifiable*, ii) *to communicate* and iii) *to interact*. When objects can sense the environment and communicate, they become tools for understanding complexity and responding to it [6]. IoT is considered as being one of the key enablers for enhancing CE at large [3].

Advancement in digital technologies is making the current linear take-make-dispose economy more and more efficient, but it still fails to address resource and natural capital issues. However, this new connectivity between digital technologies and economy also offers the possibility to re-think the underlying system and support the development of CE. By combining the principles of CE with IoT and cloud technologies, greater opportunity may arise to scale new business models more effectively [7].

In this article, we present the current implementation of a CE tool rental service and outline a scenario suggesting the possible future of the tool rental service. The envisioned tool rental scenario offers understanding on the potential of digital technologies and helps stakeholders to identify increasingly sustainable and circular business models. The remainder of this article is organized as follows: Section II presents the main principles of CE and the benefits that digitalization can provide. This is followed by representative overview of potential IoT and cloud computing technologies to be capitalized on the CE business. In Section IV, we describe the current deployment of the tool rental service, as well as develop the scenario for the future developments. Finally, Section V concludes the paper and provides some directions for future work.

II. CIRCULAR ECONOMY AND DIGITALIZATION

A circular economy is commonly defined as an industrial system that is restorative or regenerative by intention and design [8], [9]. In CE, new business models are developed to reduce the need for virgin raw materials and to generate sustainable growth. The basic approach of CE is to eliminate waste by designing out of waste. Products are designed and optimized for a cycle of disassembly, reuse and refurbishment, or recycling, with the understanding that economic growth is based on reuse of material reclaimed from end-of-life products rather than extraction of resources. Circular design makes products easier to disassemble in preparation for their next round trip. Reuse means the use of a product again for the same purpose in its original form or with little enhancement or change. Refurbishment means a process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure, and making 'cosmetic' changes to update the appearance of a product, such as cleaning, changing fabric, painting or refinishing. Any subsequent warranty is generally less than issued for a new or a remanufactured product, but the warranty is likely to cover the whole product (unlike repair). Accordingly, the performance may be less than as-new [2].

In CE, the concept of *user* replaces that of *consumer*. Unlike today, when a consumer buys, owns and disposes of a product, in CE, durable products are leased, rented or shared whenever possible [2]. If goods are sold, new models and incentives motivate consumers (users) to return or reuse the products or their components and materials at the end of their primary use. New performance-based business models are instrumental in translating products designed for reuse into attractive value proposals.

Digitalization's role as an important enabler of CE is widely accepted. One major benefit is that digitalization enables building visibility and intelligence into products and assets. Intelligence can be knowledge of the location, condition or availability of assets or materials [7]. Knowledge of the product location enables increased product accessibility and increases the product looping. Especially reverse logistics planning becomes easier. Knowledge of the product condition enables predictive and condition-based maintenance, advanced diagnostics and prognostics of the components and products. Predictive maintenance increases product reliability and availability and enables further remanufacturing with the historical knowledge of the product in order to ensure future lifetime and guarantee the quality of remanufactured products. Knowledge of the availability of the product allows, for instance shared use cases through digital platforms and market places, and improved recycling.

Digitalization also boosts the transformation towards service based business models [2], [3]. Thus, the shift towards product service systems (PSS) is suggested as being one of the key solutions in accelerating the transformation towards CE, and digitalization is a major enabler in this process [4]. RFID technology enables information collection on the usage history of products, which plays a central role in PSS-related business models, for example. This enables tracking the quality of returned products and facilitating the return flows into product life cycle management [10]. Also different digital technologies, such as utilization of artificial intelligence (AI) and data science bring novel ways to improve product life time, availability and looping. Moreover, digitalization can offer transparent access to data on products' resource consumption enabling optimization of product life cycles [11]

CE systems with interrelated cycles consist of large amounts of data. Digitalization provides new means to access this data. Decisions need to be made regarding the products' lifecycle stages, how waste materials should be reused, what type of logistical arrangements are needed and who are the actors involved in the value network. Understanding the value proposition in the value networks is essential [12]. Digitalization provides opportunities for the virtualization of distribution channels. Value can be delivered to the customers through digital channels, e.g., online shops and digital products. This can lead to reduce environmental impact and novel circular business models [12].

In CE, the coordination of material and information flows is crucial. Information about quantity and quality of products and their raw material contents need to be collected and retained. Digital technologies enable keeping the data together with materials in the cycle and make it possible to use waste as a resource [13].

Integration of digital intelligence provides opportunities to distribute knowledge, structure, ownership and different levels of customization. This allows more connected and durable relationships with the customers and end users. In addition, digital solutions enable circular business models through automated monitoring, control and optimization of resources and material flows [13]. CE also requires system knowledge and understanding for optimizing business models during the product and service life cycle. Overall, this is one of the advantages of digitalization: the capability to optimize big data and utilize artificial intelligence for solving circular challenges.

Yet, in order to gain all the above-mentioned benefits, there are still many challenges to be solved and gaps hindering digital technology-aided circular business models implementation. Overall, IoT technologies, cloud computing and digitalization in general have potential to disrupt current prevailing linear business models [14]. For instance, the incumbents of the media and music industries have experienced the enormous forces of start-ups' new business models based on digital data and technologies.

III. Sensors and communication

The concept of combining computers, sensors and networks to monitor and control devices has existed for decades [15]. Advancements in digital technologies are not only limited to embedded technologies, wireless communication protocols and small devices, but also huge amounts of data are being generated by these devices and can be utilized to improve businesses. In this section, we give a representative overview of available IoT technologies affecting CE.

A. Sensors

Recent improvements in wireless technologies and electronics have enabled the development of low-cost, low power and multifunctional sensors that are small in size and can communicate in short distances. Typically, these sensors consist of sensing, data processing and communication components. The deployment of sensors is mainly driven by three factors; decreasing price, improving computational power and smaller size, which enables their integration into smartphones and other small devices [16].

Sensors are often categorized based on their power sources, i.e., *active* or *passive*. Active sensors emit energy in environment, while passive sensors passively receive energy that is produced externally to the device. Passive sensors require less energy, but active sensors can be used in harsh environmental conditions. Table I lists typical sensor types based on their functions [17].

The main challenges related to the use of sensors are power consumption, data security and interoperability. Many IoT applications need to run for several years over batteries, but charging and replacement may pose some issues especially in remote areas. However, recent advances in the fields of nano-scale accumulators and energy harvesting techniques have become promising choices [6]. IoT sensors are vulnerable for malicious attacks for several reasons; first, sensors are most of the time unattended that makes them easy to attack. Second, wireless communications make eavesdropping very easy and third, low energy and computing resources do not allow complex security implementations [18].

B. Networking

Data collected with sensors need to be communicated to other locations for integration and analytics. Internet Protocol (IP) is an open protocol that provides unique addresses to various internet-connected devices. IP networking represents a scalable and platform-independent technology having interoperability as the most essential objective. There are two IP versions, IP version 4 (IPv4) and IP version 6 (IPv6), which is the next generation protocol designed to provide several advantages over IPv4 [19].

TABLE I. DIFFERENT SENSOR TYPES.

Sensor types	Description
Temperature	Temperature sensor measures the amount of heat or cold. Temperature sensing is essential in quality control of an environment or internal factors.
Humidity	Humidity sensor detects the presence of water in the air or a mass. Humidity sensing in important for instance in industrial processes and human comfort.
Position	Position sensor measures the absolute or relative position of an object.
Occupancy	Occupancy sensor detects the presence of an object (e.g., people) even when they are stationary.
Motion	Motion sensor detects moving objects, for instance people or animals.
Velocity	Velocity sensor measures how fast the object moves or rotates.
Acceleration	Acceleration sensor measures changes in the velocity of objects that means how fast the object’s speed changes.
Pressure	Pressure sensor measures the physical force applied by liquids or gases.
Flow	Flow sensor measures the rate of liquid or gas movement. Flow sensing is used especially in medical technology, industrial and building automation.
Sound	Sound sensor measures the level of noise in the environment.
Light	Light sensor measures the change or presence of light in the environment.
Chemical	Chemical sensor measures the concentration of chemicals, such as carbon dioxide.

TABLE II. COMMON NETWORK TECHNOLOGIES BY CONNECTION TYPES.

Connection type	Network type		
	PAN	***LAN***	***WAN***
Wired	USB	Ethernet	
Wireless	Bluetooth, RFID, NFC, Wi-Fi, ZigBee	Wi-Fi, WiMAX	WiMAX, LoRaWAN, Cellular technologies

Network technologies can be classified as wired or wireless. The main advantage of a wireless network is that users and devices can move around freely within the area of the network and get an internet connection, while wired connections are still useful for relatively more reliable, secured and high-volume network routes. The choice of technology depends mostly on the physical range to be covered [20]. When devices communicate with other nearby devices, they can use wireless personal area network (PAN**)** technologies. A local area network (LAN) connects networked devices over a limited area, such as an office building, school or home. When data have to be transferred over a large geographical distance, wide area network (WAN) technologies are used. The Internet is an example of the world’s largest WAN.

The most common short-range wireless network technologies are Bluetooth [21], Near Field Communication (NFC) [22], Radio Frequency Identification (RFID) [23], Wi-Fi [24] and ZigBee [25]. Respectively, the most commonly employed wider range wireless network technologies are cellular technology, such as 3G or 4G, Low Power Wide Area Network (LoRaWAN) [26] and WiMAX [27]. Table II gives an overview of the mentioned networking technologies by their connection types [28].

The main challenges related to adoption of network technologies are associated with security, network interconnections and power consumption. Security will be a major concern wherever networks are deployed. Data transmission can be relied on several networks, such as Ethernet, cellular or other wireless networks, and different network technologies are often connected with gateways [29]. In addition to security, these interconnections pose challenges by adding complexity. In order to tackle the problem networked devices have with power consumption, energy-efficient networking is explored in research communities [30].

C. Data communication

Data communication focuses on how the data is streaming from the sensors towards the databases and application back-ends. The data communication includes a set of protocols that have been built for high volumes and large networks of devices. Constrained processing capabilities and limited battery resources restrict communication in sensor systems. Typical sensor application and data communication protocols considering processing capability and energy consumption are the following three [31]:

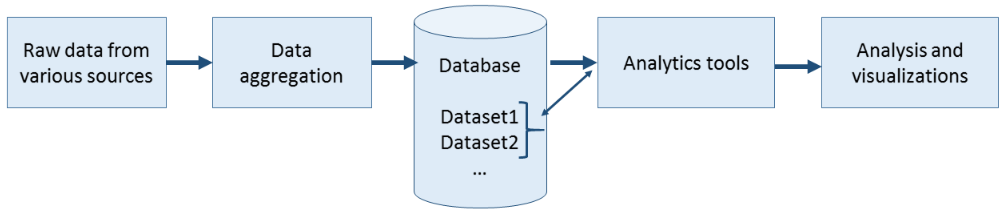

Figure 1. High-level overview of data processing.

- Message Queue Telemetry Transport (MQTT), which is a lightweight publish/subscribe based message protocol especially well-suited for running on limited computational power and lean network connectivity.
- Constrained Application Protocol (CoAP), which is designed specifically for machine-to-machine (M2M) applications, such as building and energy automation.
- Hypertext Transfer Protocol (HTTP), which is attractive option because of availability and compatibility of the legacy HTTP-stack on various platforms.

In many IoT solutions and sensor data platforms, the observational data from sensors is typically stored in simple and convenient data formats, which are easily accessible and already supported in many programming languages and common software development frameworks [32]. The most important examples of such data formats commonly applied in sensor systems are JSON, XML and CSV.

IV. CLOUD COMPUTING

The previous Section III presented the sensor, networking and data communication technologies that are relevant for IoT applications. Figure 1 depicts a simplified high-level data handling process for IoT applications receiving data from multiple data sources and in different data formats. The process of extracting and transforming the data into a suitable format and storing it in databases is often called data aggregation. The data aggregation prepares the data for analysis. This section focuses on cloud computing, which complements the previous IoT technologies in terms of data processing, storage and analysis.

A. Cloud platforms

We define an IoT platform as a middleware and infrastructure that enables interaction between the end-users and physical objects [32]. The IoT platform can be either local or provisioned from a cloud as illustrated in Figure 2. With cloud technology, platform's computation and storage resources can be made available on a need basis, without requiring major investment in new hardware or programming. Platform-as-a-Service (PaaS) is a category of cloud computing services for developing, managing and delivering applications. Software-as-a-Service (SaaS), on the other hand, provides an access to a cloud-based software or applications through which data can be stored and analyzed [33].

The most cloud platforms are implemented with the Representational State Transfer Application Programming Interface (REST API) [32]. Employing REST API also gives the advantage of easy integration with other web services, cloud environments and data processing toolchains. Thus, REST-based CoAP and HTTP are widely utilized data communication solutions to interconnect devices to the IoT platform.

Many vendors, such as Microsoft, HP, IBM and Oracle, provide commercial cloud-based IoT platforms for connecting sensors and actuators to the Internet. In addition, several open-source IoT platforms are available and often propose their own communication or middleware solutions. Mineraud et al. [32] provides an extensive evaluation of a number of available proprietary as well as open-source IoT platforms.

The main challenges of cloud platforms are associated with security, integration of multifold technologies, data ownership and data processing [32]. Efficient security mechanisms are essential for IoT platforms because interactions between different objects, as well as with humans, must be secured [18]. Furthermore, information produced from data is a threat for privacy and anonymity of users must be retained [34]. The interaction of IoT platforms and sensing devices is hindered by various technologies and missing de-facto communication standards. Currently, the interoperability issues are tackled by gateways, which support new types of devices (see Figure 2). The ownership of created

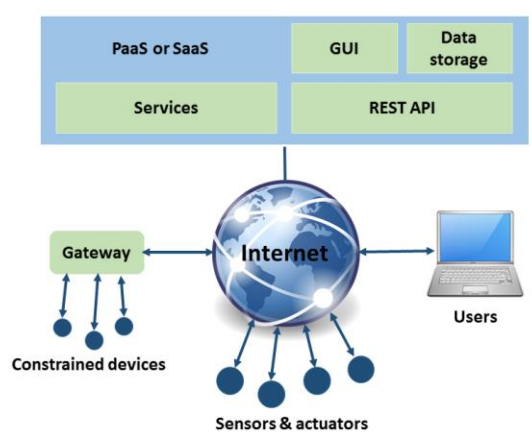

Figure 2. Cloud-based platform [27].

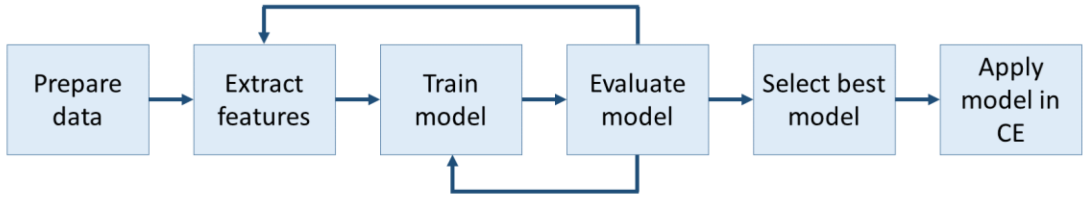

Figure 3. Machine Learning process in circular economy.

data is also a complex issue and regulation varies depending on whether the data is personal or machine-generated.

B. *Data processing and storage*

The key step for a successful analysis and use of any data is an organized and systematic approach to collecting, arranging, and presenting the incoming data [35]. Data processing methods can be divided in batch and stream processing. *Batch processing* starts with data acquisition and storing and continues with processing of the stored data [33]. For instance, Hadoop [36] is an open source batch processing framework targeted for distributed data storage and processing of unstructured data. Hadoop employs the MapReduce programming model for the processing of large-scale data clusters [37]. Hadoop Distributed File System is optimized to store large amounts of data. Another example of batch processing framework is Apache Spark [38], which is also capable of stream processing.

Especially large volumes of data and new IoT applications require real-time processing, where data items are processed as soon as they become available. This is called *stream processing* and it facilitates real-time action on the data, as well as filtering and aggregating it for efficient storage [33]. Open-source frameworks, such as the Apache tools Samza [39] and Storm [40] have been created for real-time or near real-time processing of streaming data. Flink [41], on the other hand, is an open-source hybrid framework for stream processing, which can also manage batch processing.

Compared to relational databases, requirements on performance and scalability typically presume non-relational databases. NoSQL (Not only SQL) databases are designed for storing unstructured data. Popular databases for storing streaming data are Apache Cassandra [42] and HBase [43]. True to form, all data processing frameworks and storing tools have different benefits and limitations, and the selection of tools depends on application.

C. *Data analytics*

Data analytics refers to examining of raw data with the purpose of refining this data as useful information that can be used as knowledge. Data analytics can be divided into three different categories: a) *descriptive* analytics describing what the data looks like, b) *predictive* analytics predicting what is going to happen, and c) *prescriptive* analytics describing what should happen to reach the goal [44].

Machine learning refers to system's ability to learn without being explicitly programmed. Machine learning explores the development of algorithms that can learn from and make predictions on data. Machine learning methods are often categorized as supervised or unsupervised. *Supervised learning* can apply what has been learned in the past to new data. *Unsupervised learning* can draw inferences from datasets [45].

Machine learning process is depicted in Figure 3. The process starts with data preparation. In this phase, the available raw data is visualized to get an overview of the data. The data may require some pre-processing actions, such as scaling, normalization and actions on missing data. The data is split in two parts, from which the first part is used for training and second part for testing. In the second phase, the most relevant features (i.e., variables) are selected. These features are used in construction of an accurate predictive model from various machine learning algorithm candidates.

Next, the chosen machine leaning algorithms are trained by using the training dataset. In the evaluation phase, the quality of the trained model is assessed with the test dataset. The target of the evaluation is to test the performance of the data model with testing dataset that has not been used for training the model. Approximately 20 - 30 % of the original data is used for the evaluation purposes. Another commonly used method is to leave a part of the whole dataset as test dataset, while the rest is used as training dataset, and repeat the process over the whole dataset. The method is called cross-validation. Before selecting the best solution, there might be several iteration cycles from feature extraction to model evaluation. Finally, the best model can be used for the target application in CE. The function performed by the model can relate to detecting a certain pattern in real time from sensor data or conducting a prediction based on the trend or pattern of the past data.

Different data analysis techniques are used based on the type of the addressed problem. Classification is a supervised machine learning technique, which produces a set of models or functions that distinguish dataset into different classes. The purpose is to predict the class for objects whose class is not known. There are plenty of methods that can be used for classifying the data, such as decision trees, frame- or rule-based expert systems, neural networks, Bayesian network and support vector machines. Clustering is typically an unsupervised learning technique, which divides dataset into meaningful groups having similar patterns. Clustering is a common technique for statistical data analysis and used for example by e-commerce, industry and health care sectors [46], [47].

V. Tool rental service

In this section, we describe how the previously presented digital technologies, namely sensors, cloud platforms and data analytics can be applied to a tool rental service to promote CE. We present a rapid experiment of the tool rental service and develop a scenario envisioning the possible future of the tool rental service. Our aim is to provide understanding on the possibilities and benefits of digital technologies for sustainable and circular business models. In general, digital technologies and better utilization of digital data can build visibility and intelligence into products and services.

A. Approach and data collection

Our AARRE project (Capitalising on Invisible Value - User-driven Business Models in the Emerging Circular Economy) explored user-driven circular business models and collaborated with multiple Finnish companies, Finnish organizations and Finnish decision makers in the CE field. The idea of a tool rental service is to offer an alternative for purchasing of tools, such as electric tools and cleaning equipment, which are used infrequently in urban economy. This kind of sharing economy can be an ecological option in certain conditions and on the other hand, facilitates the storage problem of goods in urban housing [48]. The goal of our empirical study is to provide input for the discussion on how to disrupt current prevailing linear business models by employing digital data and IoT technologies.

The planning and rapid experimenting of the tool rental scenario is based on several discussions with eight (8) AARRE project researchers, one start-up entrepreneur, and various companies. We also use interviews of nine (9) users and potential users of Liiteri, and Owela innovation tool results as a background material.

In addition, prior to the experimentation, a consumer panel was held in the project in order to identify current and future needs, ideas, enablers and barriers related to CE business models. There were 42 panelists divided into 5 groups. The discussion in each group was led by 1 - 2 scientists and based on a uniform list of questions. Several issues related to renting, leasing, borrowing and sharing were identified where IoT can be an enabler. Based on the discussions, the identified barriers related to renting, leasing, borrowing and sharing, are current lack of information on selection, availability, location and condition of the items. There is also a need for some additional information, such as instructions for use, as well as a need to monitor the usage in some cases. Tracking and tracing information in the logistics process would make renting easier and more cost-efficient. Technology could also support in providing a rating system concerning both the users and service providers.

B. Current deployment of the tool rental service

Our AARRE project participated in the design and implementation of a rapid experimental tool rental service called Liiteri [49] in collaboration with Finnish IT-startup CoReorient [50] and hardware store K-Rauta. The other co-operation partners were Helsinki Region Environmental Services Authority HSY, Technology Industries of Finland, SER-kierrätys, City of Espoo, Purjebägit Oy, Kierrätysverkko Oy, Metrosuutarit.fi, Pyörähuoltoovelle.fi and Kauppahalli24.fi.

Liiteri is an online platform where users can rent electric tools and house cleaning equipment. By registering to the Liiteri service, the user can choose the desired product and renting date via the online platform. The rental payment is made via the online service at the same time with product selection. When the payment has been processed, the user gets an access code to the 24/7 Liiteri self-service point, which is an intelligent container in the city centre of Helsinki. The user can pick up the rented gear any time from the Liiteri self-service point located at a central place of public transport connections. Alternatively, the user can choose a crowdsourced PiggyBaggy home delivery service [51]. An initial experiment to examine the utility of the Liiteri tool rental service was conducted and reported in another study [46].

C. Scenario for the tool rental service

In this section, we describe a future business scenario for the previously described Liiteri tool rental service. The scenario complements the available Liiteri tool rental service and aims to provide information for companies about the future possibilities of digital data collection, processing and analytics. Figure 4 depicts the envisioned tool rental service scenario. The data is collected by various means, such as sensors, mobile application, web services and data logs. Depending on the data and its application, different data processing and storing options can be used. Respectively, the choices of data analytics methods and visualizations are always dependent on the target application.

1) Personalized real-time services

Asset tracking refers to the method, which can be used to provide information on the location of physical equipment by using scanning a barcode or using location aware technologies, such as GPS, RFID or Bluetooth Low Energy (BLE). The asset tracking can be real-time or based on connected checkpoints. A node that is aware of its location and can send signals to smartphones or other mobile devices is called a beacon. BLE-based beacons are a worthy choice for improving shopping experience as they have high accuracy and support by the majority of mobile devices [52]. User's smartphone can interact with beacons placed in the Liiteri self-service point via a Liiteri mobile application (later referred to as the Liiteri app). BLE-based *beacons can be used for mobile door opening* when entering the 24/7 Liiteri self-service point [53].

Furthermore, the beacons can be utilized in *store navigation*. The beacons can enable users to be recognized in real-time when entering the 24/7 Liiteri self-service point and help them find easily the selected tool or other rented gear with nearby push notifications feature. A payment for the selected product can be discharged using a *beacon-based mobile payment* or a more conventional online payment service provided by the Liiteri app.

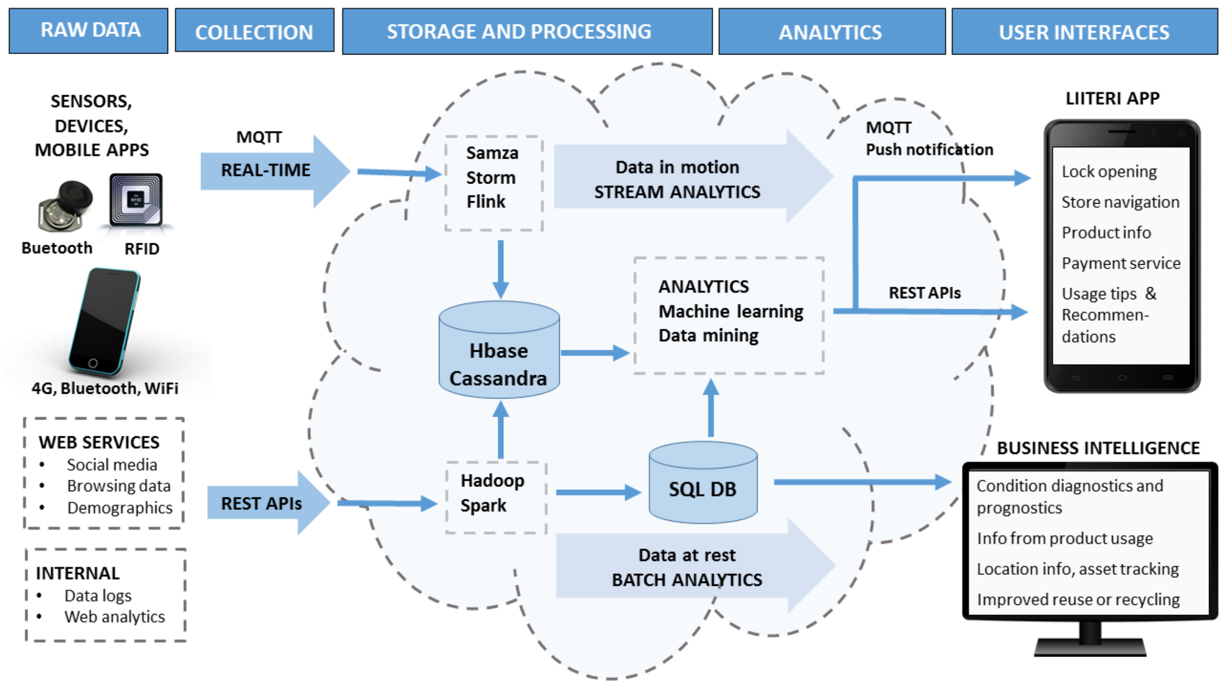

Figure 4. IoT-enabled tool rental service business scenario.

2) Other personalized services

At home, the users can be provided with a *guided usage service* by scanning the tool (equipped with barcode or RFID tag) with their phone, and even a guided replacement service in case of a broken part can be possible. The data from web services, such as social media, can be integrated with Liiteri data logs to provide other personalized services via REST APIs. For instance, the rental profile including demographic data and browsing history from the Liiteri app can be further analysed for *personalized recommendations*. The Liiteri app can also allow the users to *access product information and reviews* to help them make their decision. In these services, the data is analysed in batches and possible data processing frameworks can be Apache Hadoop or Spark. For data storage, Hadoop file storage or HBase are possible candidates.

The tool availability and location information can be utilized to *provide a connection with next user*. This promotes collaboration among users and facilitates *crowdsourced delivery of tools* from user to user. During the delivery process, communication can be handled via the Liiteri app. *The deliverer can earn points*, which she or he can spend for the tool rental or redeem for cash. Home delivery service of the tools, in turn, can utilize the real-time navigation information and the customer's location information for route planning and *optimization of delivery routes* to reduce driving time, fuel consumption and exhaust gases.

3) Condition-based maintenance

Sensors can measure for example acceleration, temperature, vibration and humidity of tools or parts of the tools. The sensor data can be exploited in business intelligence in many ways, such as in condition-based maintenance (CBM). The condition-based maintenance is a maintenance procedure based on the information collected through condition monitoring and can be used for *diagnostics* and *prognostics* [54]. Prognostics based maintenance is often called as predictive maintenance. The goal of condition-based maintenance is to increase the lifetime of tools, improve the maintenance efficiency and safety. The condition-based maintenance of the tools can employ streaming data from multiple sensors, both from component or system level. This scenario is composed of various tools in different locations and cloud computing for (near) real-time monitoring of these tools.

The tools can be equipped with affordable sensors connected to the Liiteri cloud-based platform using cellular networks. The data streams require real-time processing for assessing current failures (diagnostics). On the other hand, batch processing is needed for predicting possible future failures (prognostics). A possible solution for data processing can be Apache Spark or Flink, which are hybrid platforms and capable of stream and batch processing of data. NoSQL database, for instance HBase or Cassandra can be used for data storage. Different machine learning or data mining techniques, such as classification or regression analysis can be used for diagnostics and prognostics purposes. Automatic failure diagnostics can turn refurbishment into a potential and accessible option. A trivial consequence from refurbishment and increasing the lifetime of tools is decreasing the use of natural resources and waste.

TABLE III. SERVICES BASED ON THEIR INTELLIGENCE TYPES.

Intelligence type	Service	Description
Knowledge on location	Mobile door opening	Beacon-based service for mobile door opening when entering the 24/7 Liiteri self-service point.
	Mobile payment	Beacon-based mobile payment service for the selected product.
	Store navigation	Beacon-based real-time navigation service.
	Guided usage	Basecon-based guided usage service for the rented tool.
	Optimization of delivery route	Optimization of delivery routes based on real-time navigation information and the next user's location information.
Knowledge on condition	Diagnostics	Real-time service for assessing current failures.
	Predictive maintenance	Maintenance service based on predicting future failures.
	Decision support for future loops	Prognostics service for predicting RUL to support on decision between the reuse, remanufacture or recycling.
	Improved product design	Design service based on tool usage and user feedback data.
Knowledge on availability	Crowdsourced delivery of tools	Service based on tool availability and location information to provide a connection with next user.

4) *Improved reuse, remanufacture and recycling*

A prognostics model employing machine learning can be developed for predicting a Remaining Useful Lifetime (RUL) and considering sustainability aspects in decision-making, i.e., deciding when maintenance is economically viable, environmentally bearable and equitable compared to reuse, remanufacture or recycle [55]. In this scenario, batch processing is used, and for instance Apache Hadoop or Spark are possible data processing options. For data storage, HBase would be a good choice.

The main idea of predicting remaining useful lifetime is to build a machine learning model for normal and failure events based on one or more features, which are in this case failure predicting variables, such as rising temperature or unusual vibration. The analysis results help to decide between the *reuse, remanufacture or recycling* activities in order to maintain both economic and environmental value of the tools or their parts as high as possible. In addition, the tool usage data collected with sensors and the user feedback can be analysed *to improve future product design and performance*.

IoT and cloud computing creates visibility and intelligence into assets. As described in Section II, this intelligence can be knowledge of the location, condition or availability of the tools. Table III lists the envisioned services according to their intelligence categories as introduced in [7].

VI. CONCLUSION AND FUTURE WORK

IoT technologies and digitalization in general enable novel business models based on CE, offering a significant potential to disrupt current prevailing linear business models [56]. As a case study to evaluate the hypothesis, we presented an instance of a CE tool rental service and outlined a scenario suggesting the possible future of the concept.

A. *Discussion*

Tool sharing itself is not a totally novel idea and for instance city of Toronto has a tool library [57]. The Toronto tool library is a centralized warehouse where people can store and share their tools to the local neighborhood with an annual membership payment. The novelty of our tool rental service lies on more advanced use of technology. The envisioned tool rental service scenario uses sensors, networking, cloud computing, and data analytics for selling services instead of goods, for designing products for regeneration and for creating added value through services. Generally, offering services instead of selling goods reduces the environmental footprint of product manufacturing and the private ownership of goods. The target of this study was to awake discussion among companies on how to create CE business by employing digital data, IoT and cloud computing.

Organizing and managing the growing amount of data from increasing number of sources is crucial for a successful novel CE service. A notable data analytics challenge is related to heterogeneous data sources and extracting data from different data storage locations in large scale. The chosen methods need to overcome variety, heterogeneity and noise of the data. Data storage is required to be highly robust and resilient to failures. Using the available data to a maximum benefit requires a comprehensive understanding of the meaning, behavior, and relations of the data. Data mining is typically a human-operated process, where the data is explored by supervised or unsupervised methods, aiming to gain understanding and to find patterns or models that can lead to a business advantage. Acquired models can then be deployed to automatically process the dedicated part of the data stream or storage.

Our current database implementation is centralized but multidisciplinary colloboration towards more circular businesses could beneftit from the use of decentralized databases. Blockchain technology is a decentralized database that allows for the chronological recording and secure storage of transaction data. Blockchains can be used to register tool rentals and transfers between tool renters making system more transparent and increasing trust. Even though blockchains provide pseudonymity meaning that transactions are transparent but not explicitly connected to individuals, sensitive information should not be shared [58].

When applying IoT and cloud computing in real-world implementations information security must always be considered. Information security and privacy procedures, in terms of data integrity, access control, and system availability, need to be in place to protect the information and service provisioning of relevant actors [18]. Moreover, the scenario raises questions about who owns the created data, on which terms the data can be shared with others, and what kind of legislation should be in place to prevent the sharing of sensitive data. General Data Protection Regulation (GDPR) is an EU wide regulation for data privacy that aims to protect all EU citizens' personal data and regulate the international business related to the personal data [59]. Before the commercial implementation of the envisioned services, considerations regarding data protection and privacy must be done according to the GDPR. All personal data must be protected, stored and processed appropriately.

In order to create future services that are increasingly capable of adapting to the user and the surrounding external conditions, development in technologies enabling learning from data have become pivotal. The users are individuals, whose needs and preferences vary. The service provider operates on a large population, but gains an advantage from being able to adapt to the user and threat each one individually. There are several use cases in CE, where machine learning could be applied in general. Related to the service addressed in this study, the most potential usages include detecting the user preferences in current context in order to guide suitable actions for the user, and modeling different types of users having varying types of purchase behavior. As an additional benefit, adapting to the user enables targeting marketing or commercials for the user based on their past behavior. Predicting product demand highly accurately becomes feasible, which facilitates further cost savings. Moreover, AI and machine learning methods present a considerable prospect in materials and products process flow optimization, which becomes especially crucial when the system is scaled up.

B. Limitations and future work

As in every research, there are some noteworthy limitations with this study. The scenario planning has been qualitative and it includes researchers' and interviewees' subjective interpretation. The previous study [48] examined the utility of the Liiteri tool rental service and the results indicated that renting could be an attractive choice to consumers, if crucial consumer expectations are identified and met. This attitude change is partly attributable to technological improvements, such as widespread digital cloud platforms, which make sharing of goods easier. On the other hand, especially young people prefer services to ownership of goods.

In order to proceed towards commercial utilization of the presented concept, further work on the IoT-enabled tool rental service scenario includes addressing multiple technical, usability, and profitability aspects, in addition to the environmental viewpoint. The main technological challenges include the overall cost-efficient logistics on large scale, data security, interoperability of IoT sub-systems, and interface with the consumers. The usability of the service must meet or exceed the level of current modern competing e-commerce platforms. Overall, the business challenges are the same as for e-commerce and retail services in general. To be commercially viable, the service must maximize the user satisfaction and minimize the costs through intelligent use of digital technologies.

Future work needs to evaluate which parts of the system are efficient as automated, and which parts need to be managed by human operators for an optimal profitability, usability and security. The challenges and opportunities are similar as, for example, in Amazon's automated grocery store recently deployed within their office building. The store relies on cameras and sensors to detect what shoppers take from the shelves, and what they put back. Cash registers become largely obsolete, as customers are billed after leaving the store using credit cards, based on the virtual shopping cart collected while physically shopping.

Full examination is needed on the types of products that provide most benefit from the CE service concept in terms of environmental benefit. Moreover, next steps of future research endeavours could focus on implementation of a next generation IoT-enabled CE service for a larger group of people, with the systematic collection of consumer experiences for further service improvement.

Despite the various remaining challenges, there is a growing amount of consumers that see the environmental friendliness as an added value factor. This could facilitate the accumulation of consumers in the early phases of development, towards ultimately better collaboration between the human use of technology and the environment.

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