

**4th INDUSTRIAL REVOLUTION
IN SOLID WASTE MANGMENT SECTOR**



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ABSTRACT

Development and growth of society entails growth of demand in resources. Current system determining the life cycle of products from raw materials to wastes proved to be inefficient in a long-term perspective. Sustainable development is not achievable, as present paradigm neither able to equally provide exponentially growing population with goods, nor manage waste generated from production of those goods. Taking into account, how inefficiency of resource management affects ecological situation, it becomes apparent that there is an inevitable need in taking action. Certain modern technologies like Big Data, IoT or Artificial Neural Networks have great potential to change the situation for better. Integrated usage of such technologies is considered as new industrial revolution. Fourth industrial revolution might be the lifebuoy for humanity sinking in the ocean of its own waste.

This paper is aimed to emphasize the importance of fourth industrial revolution and particularly its implementation in solid waste management. Key components of fourth industrial revolution will be studied by focusing on their technology and range of application. Also, case studies with applications of those technologies in different areas of solid waste management sector will be reviewed, to evaluate benefits from implementing fourth industrial revolution.

Keywords Fourth industrial revolution, solid waste management

Pages 36 pages including appendices 7 pages

Industry 4.0	Fourth industrial revolution
CE	Circular Economy
MSW	Municipal waste management
SWM	Solid waste management
MSWMS	Municipal solid waste management system
W&RM	Waste and resource management
IoT	Internet of things
CPS	Cyberphysical system
AAA	Authentication, Authorization and Accounting
CoAP	Constrained Application Protocol
ACL	Access Control List
IAM	Identify & Access Management
DTLS	Datagram Transport Layer Security
EC2	Elastic Compute Cloud
DBMS	Database Management System
BDA	Big Data Analytics
EPR	Enterprise Resource Planning
ETL	Extract, Transform and Load
SQL	Structured Query Language
NoSQL	Not Only Structured Query Language
MQTT	Message Queuing Telemetry Transport
AI	Artificial intelligence
ML	Machine learning
ANN	Artificial neural network

LIST OF ABBREVIATIONS

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CNN	Convolutional neural network
RNN	Recurrent neural network
CV	Computer vision

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1 INTRODUCTION

Purpose of this chapter is to justify why traditional waste and resource management system is inefficient, also point out main problem of linear economy model and draw parallel with take-make-dispose principle. Last part of this chapter is dedicated to description of 4th industrial revolution, as well as counter propose its principles to traditional paradigm.

1.1 PROBLEM IDENTIFICATION

Development of business provides world with new, better products and services. Expansion of manufacturing sector means a company makes more money. Totality of manufacturing companies making more money on national scale means growth of GDP, which respectively results better life quality for population. Thereby, considering rates of population growth are only increasing - building up the manufacturing business sector can be interpreted as one of primary goals for sustainable development. On the other hand, increase of manufacturing sector as it stands today results higher rates of raw material extraction, entailing more resources being wasted. The paradox is: the factor directly affecting development of mankind at the same endangers humanity along with other biological species. The mass production term exists for only about a century, however nature conservation organizations consider several consequences brought by mass production, as collapse of ecosystem on a small scale. Specifically, in comparison with 1980 global consumption of resource per capita increased by 15% and extraction of raw material almost doubled. (United Nations, 2019)

The main problem is that at the time when traditional business model was forming, people could not take account the environmental impact factor, as there were no examples to rely on. Thus, pursuit for improved life quality evolved in the model of linear economy, also known as take-make-use-dispose principle. (European Commission, p. 3, 2020) In other words, inefficient approaches of raw material extraction, poor planning of products design in terms of material lifecycle and small capabilities of waste management are fundamentals of business as usual. As follows from scheme presenting the lifecycle of global resources: out of 93 billion tons of extracted resources only 9.3 billion tons have actual lifecycle (are reused), where only 1.5 billion tons are recycled which approximately 1.61% of total amount (Appendix 1). Humanity is at the point when technologies are advanced enough to monitor and evaluate the damage caused by activities of industrialization, however the problem is that majority of business sectors are tightly bonded with such activities. Meaning that termination of those activities will negatively reflect on economy or even collapse it.

1.2 BACKGROUND

Theory of industrial revolutions was described by English historian and economist A. Toynbee. He was the first one to propose a holistic conception of industrial revolution, his works describing the phenomenon were published in 1884. Popularity of those works served as base of economic history creation which appeared in the end of 19th century and being developed till this very day.

Toynbee sets 1760 as starting point of industrial revolution, by pointing out that England did not have any great mechanical invention before that. First industrial revolution represented transition of qualified artisans who produced products by hand into workers operating machines with water wheel or steam powered engines. These innovations mostly affected textile industry, yet outcomes of mechanical production affected all the aspects of daily life. Second industrial revolution was happening in the end of 19th and beginning of 20th century, approximately from 1870 and before beginning of First World War. Unlike first one which is characterized by innovation technology, second industrial revolution was linked to improvement of existing methodologies and tools, as well as their interactions. For example, electricity replaced water and steam powers as major supply of energy to factories. Mass production was also started during second industrial revolution by application of assembly lines and interchangeable parts. Third industrial revolution similar to first one resulted development of innovations, creating of computing management systems and application of information technology speeded up, automated and increased quality of manufacturing processes. Today we are living in a time of transition to fourth industrial revolution (Figure 1).

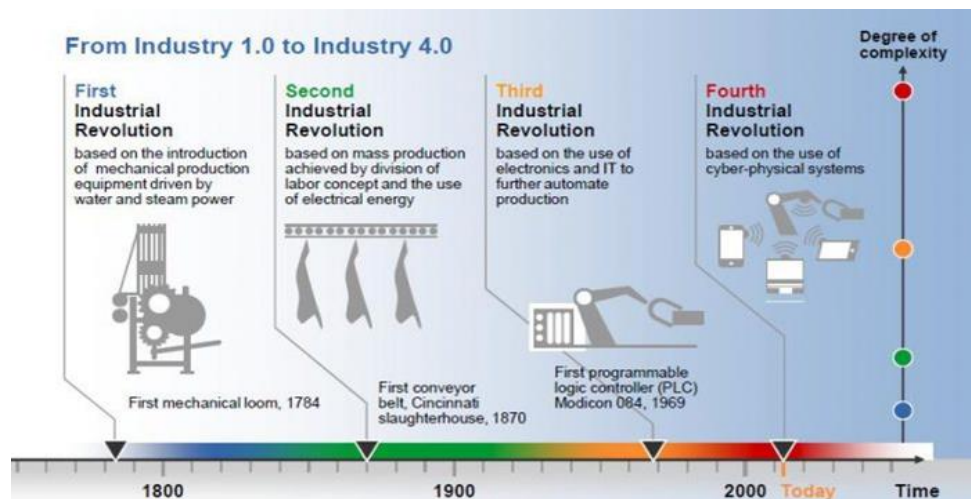


Figure 1. Timeline of industrial revolutions

1.3 **FOURTH INDUSTRIAL REVOLUTION**

Firstly, the 4th industrial revolution is not actually referred to a technological revolution. On the other hand, it follows all the requirements to be such. The basic idea remains the same – humanity is advanced enough to take a step into new technological era, changing paradigms of daily-life including business and society.

The term was officially introduced in 2011 by German authorities and entrepreneurs as a part of national high-tech strategy aimed to promote computerization and optimization of German's manufacturing industry.

Since that time, the popularization of Industry 4.0 term, as well as modern technologies resulted the concept of 4th Industrial Revolution making it a collective name for digital innovations of all kinds.

2 **TECHNOLOGIES**

During search of the materials related to Industry 4.0 topic various technologies were reviewed and ones with highest potential impact were determined. They are: Internet of Things, Big Data and Artificial Neural Networks.

This chapter focuses on description of these technologies including their history of creation, technical specifications, and application areas (excluding waste management industry).

2.1 **INTERNET OF THINGS**

Despite Internet of Things appeared as an official term only in 1999, the idea machine communication can be dated back to 1832 when Baron Schilling invented an electromagnetic telegraph. In modern understanding of communicating machines the first IoT device was invented in 1990 by John Romskey when he connected his toaster to the internet so it could be remotely switched on and off. (Postscapes, 2019)

Due to generalization in term description causes ambiguity in what can be classified as IoT from technical perspective (Figure 3). At the moment, there are several terms constantly being confused as they describe same phenomenon sometimes with different biases: IoE (Internet of Everything), WoT (Web of Things), IIoT (Industrial Internet of Things) CBS Cyber Physical System) and embedded internet. (Lasse Lueth, 2014).

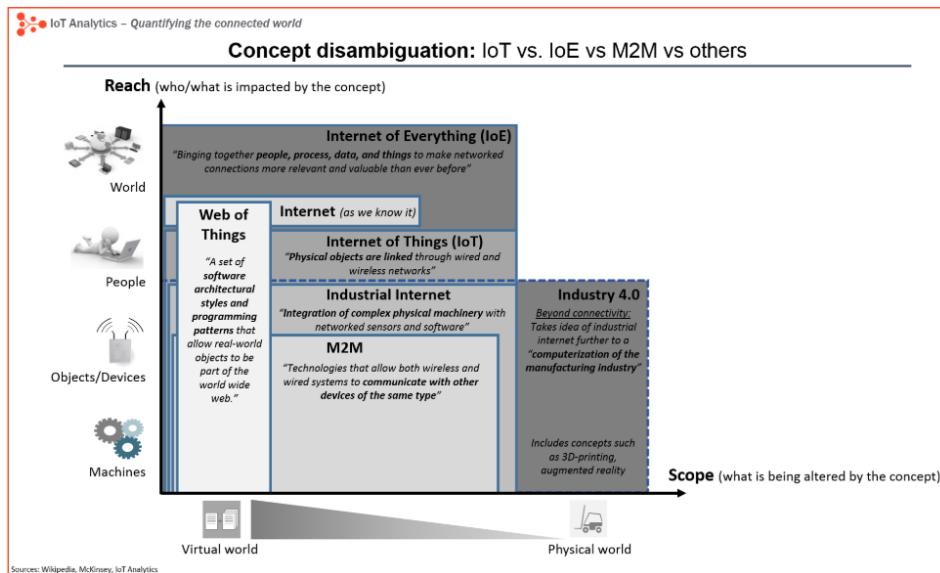


Figure 2. Concept disambiguation (Lasse Lueth, 2014)

Despite tasks or application areas the idea of all mentioned above terms determined to environment where components from physical and virtual world can transfer data and interact with each other without human intervention.

For better understanding of conventional concept, an IoT architecture can be divided into layers making it similar to OSI model (Open System Interconnection model). Figure 3 represents the general scheme which includes all layers that can be involved in an IoT solution. In practice, quantity of layers and their types are determined by area where an IoT solution is applied. (i.e. the gateway layer is not required in transport optimization, or an IoT architecture used in a smart home can stability function without powerful data distribution unlike architectures used in a factory).

As middleware, ETL and analytic layers are directly related to data management: their specifications, technologies, and principles will be more comprehensively described in the BIG DATA

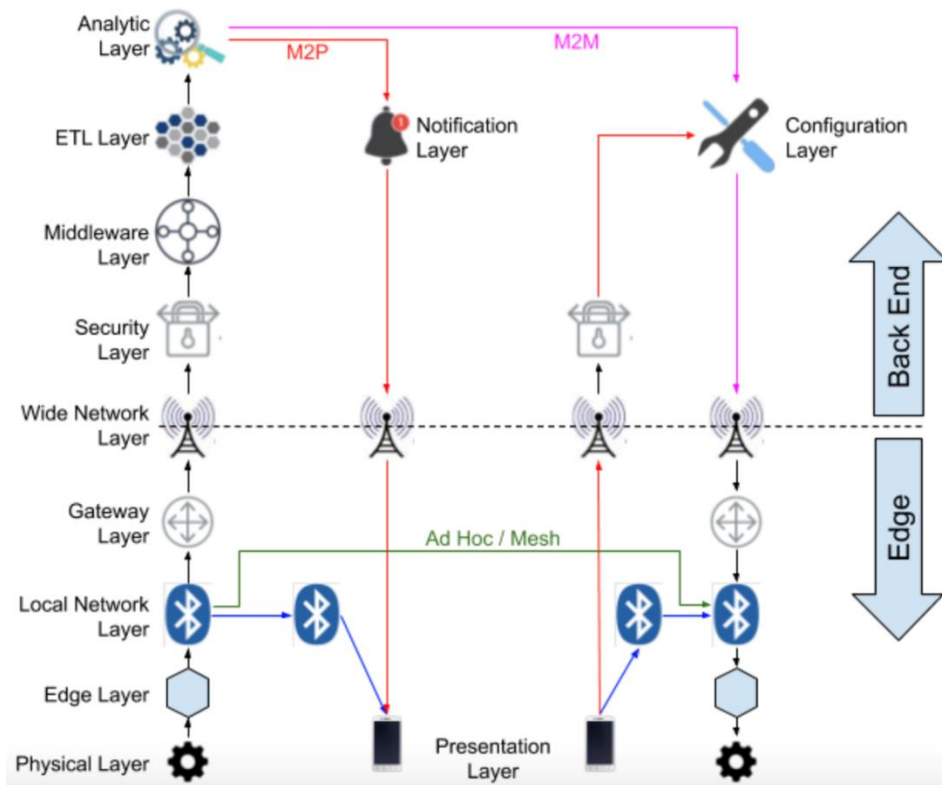


Figure 3. Layers of IoT architecture

- Physical Layer

This layer consists of data collection by sensors (RFID, GPS, PIR, cameras, microphones, electronic thermometers, etc.) And executive functions by actuators (switches, door locks, temperature controllers, water pressure controllers etc.)

- Edge Layer

This layer is often connected to a sensor or actuator and does the function of local computing, providing minimal functionality for transferring data from analog into digital format or vice versa. As shown in Figure 4 edge layer is also responsible for activating phases (connection setup, data collection phase, data receive phase and sleep phase)

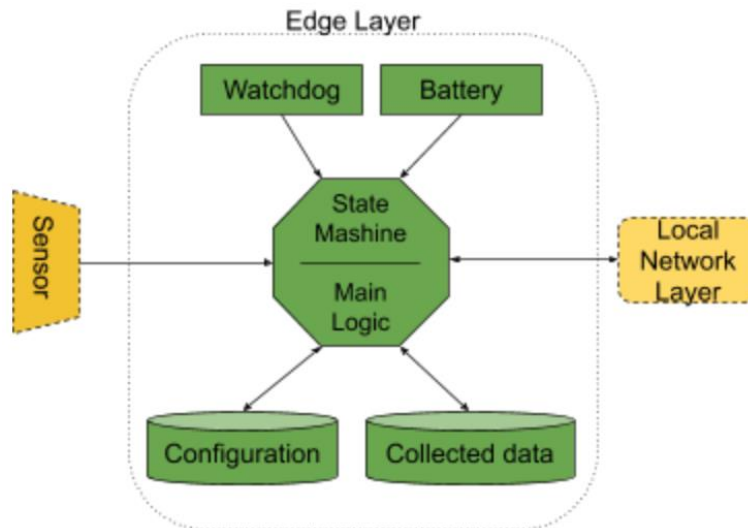


Figure 4. Edge layer scheme

- **Local Network Layer**
 Needed for peripheral communication. There are several protocols for data transfer (Radio, Ethernet, Wi-fi, LTE NFC, PLC, BLE, LoRa, ZigBee, etc.) Selection of a protocol depends on application area of an IoT solution.
- **Gateway Layer**
 This layer acts as communicator between Edge (peripheral devices) and Backend (operational server). It should implement ETL function for peripheral devices and store about their status. Also, in case of critical situation gateway layer should be able react locally (even if there is no connection to Backend).
- **Wide Network Layer**
 Is a separation between Edge and Backend parts in a system. Usually it is connected via cellular network, less of often via wired connection. It also uses LwM2M protocol as logic level of external communication. (Including DNS based balancing and positioning services, COAP - transportation protocol, DTLS – encryption connection protocol, etc.)
- **Security Layer**
 Provides data encryption and decryption, as well the AAA function. In general, security layer is usually cloud based solution like Amazon Web Services (IAM, R53 and EC2 for DTLS decryption). In manufacturing industry security is usually based on physical servers with ACL.
- **Middleware Layer**
 Function of this layer is to provide asynchronous data transfer with buffering and redistributed balance of load. Parts of this layer must correspond to principle of horizontal scalability.

- ETL Layer

This is the inner data processing layer. It is responsible for notifying other services about new data, extraction of data and standardization of its classes, also it manages data lifecycle (loading, archiving, or deleting).

- Analytic layer

Functionality of this layer is usually done by Ai or ML and its specification is depending on application area of an IoT solution. (anomaly recognition, analyzes of consumer inquires, route optimization, forecasting resource consumption, recommendations on maintenance of systems components, etc.)

- Notification Layer

This layer is only used for M2P (Machine to Person) it reacts to specified events by sending an information signal (a notification). Generally, it is done through email applications or phone services.

- Presentation Layer

Usually this layer is represented in user interfaces (weather website, mobile application for smart home management, ERP integrated applications, etc.)

- Configuration Layer

This layer is used for storing current and updated statuses for peripheral appliances (because of energy saving considerations sensors and actuators do not have constant connection with backend server, so changes in the system cannot be transmitted to edge devices immediately).

During last decade amount of IoT devices rapidly increased, nowadays such devices are being actively infiltrated in manufacturing industry for production machinery or conveyors, as quality control in automated production directly depends on amount and variation of received data. Same solutions can also be beneficial for monitoring state of manufacturing equipment, as well as general processes optimization. Internet of Things solutions are also actively used in financial, healthcare, education, and transportation sectors. (Reinsel, Grantz, Rydning, 2018, p. 24)

International Data Corporation predicts that by 2025 over 150 billion devices will be connected to global network, where most of the data will be generated real-time by IoT devices. As shown in figure 6. At the moment, approximately one fifth of total datasphere consists of data generated in real-time. By 2025 it is estimated to be 30%. And eventually majority of global data will be generated by IoT solutions applied in various business sectors. (Reinsel, et al., 2018, p. 13)

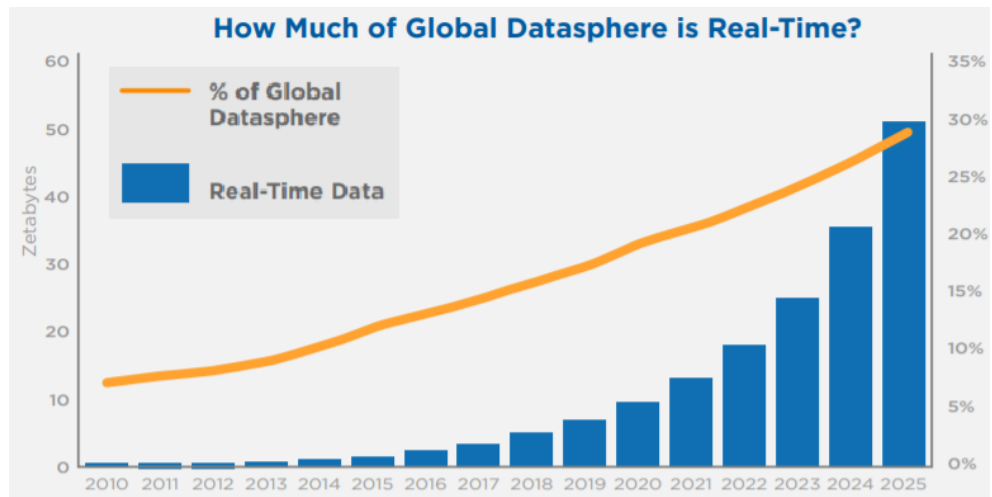


Figure 5. Real-time data (Reinsel, et al., 2018, p. 13)

Internet of things is inalienable part of 4th industrial revolution. It acts as base component in turning dataflow for beneficial use. At the current state of development importance of IoT is globally well realized both by people and governments. Also, it can be said that IoT areas related to data collection (sensors and actuators) and data transmission (networking hardware and communication protocols) are studied rather holistically. Thus, data collection and transmission technologies are satisfactorily fulfilling their function.

On the other hand, collected data should be stored for further processing. And considering current rates of global datasphere growth, as well as speed of data storing solutions becoming irrelevant – data storage may become one of the biggest challenges for humanity.

2.2 BIG DATA

Latest research in growth of datasphere showed explosive rates in comparison with previous decade. IDC (International Data Corporation) supposes that in 5 years data volume will be exaggerated 3 times reaching point of 175 zettabytes ($175 \cdot 10^{21}$ bytes). While amount of people interacting with data on daily basis will increase only by 13%. (Reinsel, et al., 2018, p.5). Statistics showing predicted data growth is displayed in Figure 7 (should this be 6).

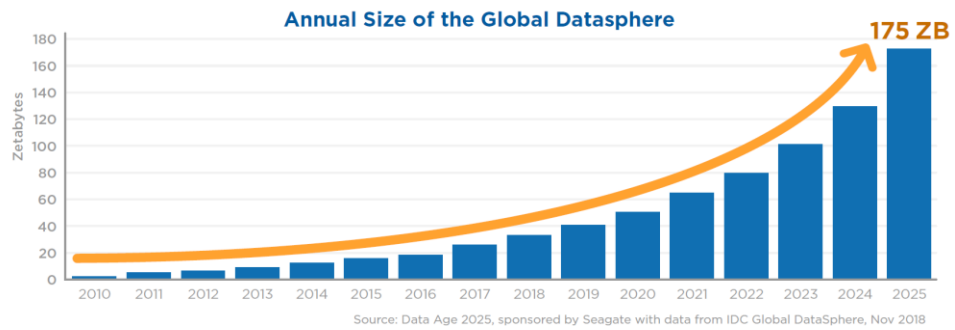


Figure 6. Annual Size of the Global Datasphere . (Reinsel, et al., 2018, p.6)

The entire world realizes the importance of data management technologies (Figure 7). Europe is a non-exception, as in January 2020 it was announced that Euro Commission sets a challenge to create a unified data market, capable of competing with current dominant technological giants like Google or Amazon. (Foo, 2020)

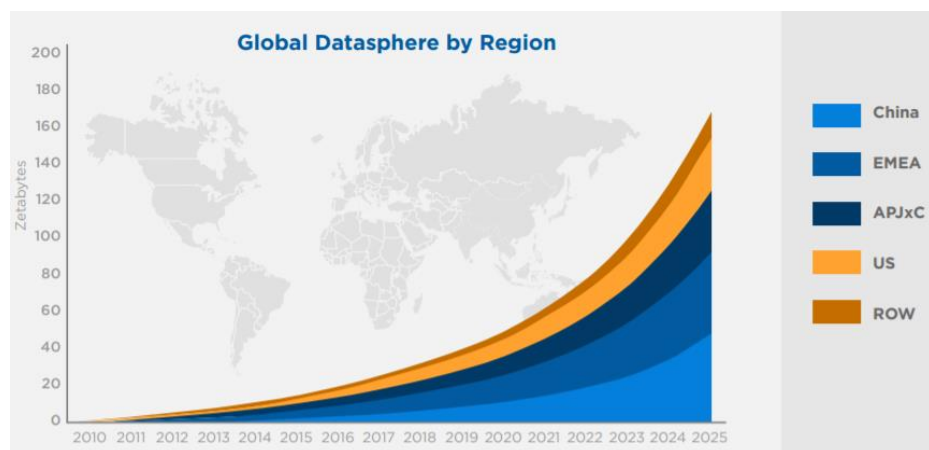


Figure 7. Size and Growth of the Global Datasphere by Region (Reinsel, et al., 2018, p. 17)

The creator of 'Big data' term is the editor of Nature magazine - Clifford Lynch. In 2008 he stated the fact that continuous growth of global information load have to be faced with new toolbox of more advanced technologies, as traditionally used DBMS (Database Management System) are unable to handle big data. (Clifford, 2008).

Therefore, it can be said that Bid Data is more related to methods and tools for data processing, than to data itself. Distinguishing feature of big data management – is ability to stably perform data distribution in conditions of sustain data growth.

As following from C. Lynch's statement: today it is clear that traditional methods of data processing are unsuitable for current rates of data

generation and those rates are that big, so a whole new approach was developed. It is called BDA (Big Data Analytics), the approach specializes on giant sets of complex and often unstructured (unlabelled) information. BDA is used to highlight important data, accurately identify trends, forecast indicators, and optimize parameters when it is physically impossible to fully review the spectrum of information. In a past few years an increase in demand for big data analytics solutions is recorded. Mostly aimed for optimization of resource management and ERP systems in industrial sector. For instance, in 2015: only 17% of companies used BDA globally, in 2017 more than half of companies worldwide (53%) were already using it. (Columbus, 2017)

Nowadays there are various systematizations used for big data processing, yet there is a set of 3 basing on principles, which are essential for every BDA solution. The principles of horizontal scalability, data locality and crash tolerance are described below.

- Data locality.
This principle means that data processing is done on the same equipment where data is stored, as transferring information between servers on a scale of big data would significantly increase costs.
- Horizontal scalability.
As theoretically amount of data which can be loaded has no limits – any system dealing with big data implies adaptive expansion of capacity (constant readiness for increase in computing power).
- Crash tolerance.
Big load of data requires big databases with big amount of computational equipment (Figure). Due to big amount of equipment there is a higher statistical chance of abnormal mistake or hardware malfunction. Thereby, crash tolerance principle is responsible for preventing failure of the whole system when such incidents happen.



Figure 8. Google's data center

As it was mentioned in 2.1, the majority of datasphere will be eventually generated in real-time of which most by Internet of Things. An IoT architecture scheme presented in Figure 3 includes several layers purposed to manage constant data streams (like video monitoring) or data with periodic peak load (like optimization of factory processes) in other words Big Data.

MapReduce was developed by Google in 2004 and was released for public use in 2014. Considered to be the very common tool for analytical tasks, yet not the fastest model used for distributed analyses of big data sets. MapReduce-based applications involves at least 3 main stages of processing.

- **Map function**
Is a specific task set by a human, the function is responsible for filtering splitted segments of input data (splits or shards). If a MapReduce model is used for word counting as shown in example (Figure) Map function is to separate text segment (input) into words and generate a key (word itself) and a value (quantity of words in segment) for each word.
- **Shuffle phase**
Is carried out without user interaction, as key and value pair is automatically requested from the map phase and then sorted regarding to the key, so different values with same key will be grouped into partitions and directed to reduce phase according to these partitions.

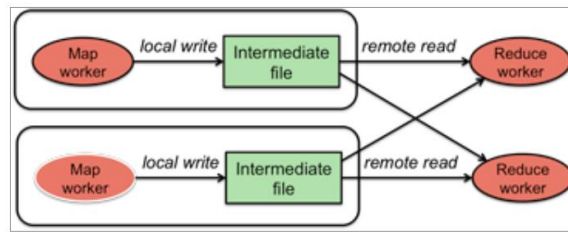


Figure 9. Sorting phase in MapReduce model (Krzyzanowski, 2011)

- Reduce function
Is applied to every partition (every key) and outputs values for each partition - the final result.

The biggest advantage of such models is the ability of all functions work independently from each other on all phases, making it possible to analyse big data parallelly and on different computers in a cluster.

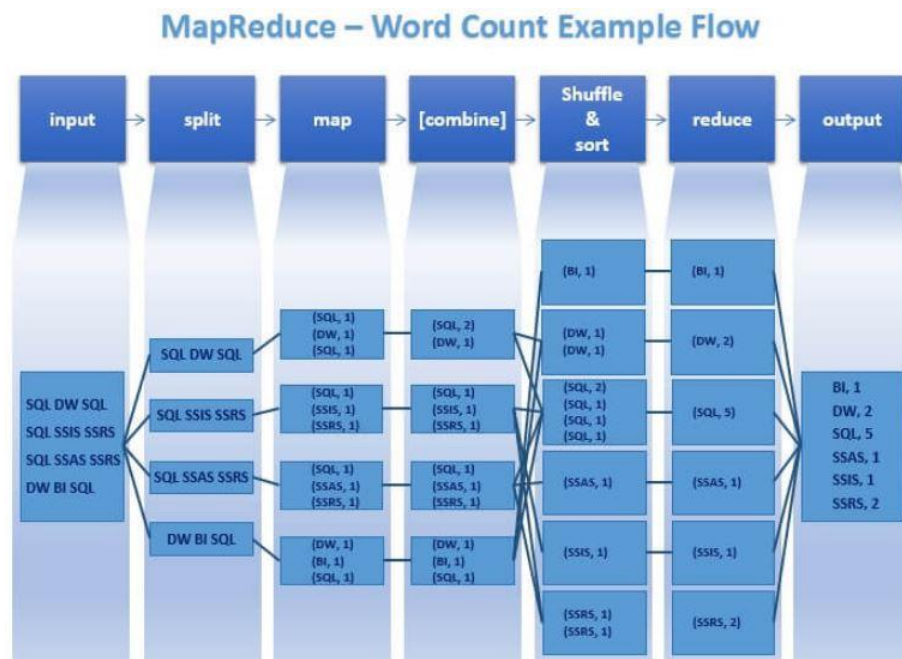


Figure 10. MapReduce model example (Wen, 2018)

2.3 ARTIFICIAL NEURAL NETWORKS

In comparison to previous technologies the research area of Artificial Neural Networks is the oldest, yet the most incomprehensible. At the same time, ANN has the biggest impact potential and its scope of applications is everything where mathematical function can be applied.

ANN (artificial neural network) appeared as a concept soon after first electronic computation machine was invented. For the first time idea of an ANN was proposed in 1943 by two researches from University of Chicago: Warren McCulloch and Walter Pitts. (Larry Hardesty, 2017).

Based on McCulloch-Pitts research the first artificial neural network which had a practical application was developed in 1959 by co-inventor of the microprocessor Marcian Hoff and his professor in Stanford University Bernard Widrow. They called it 'MADALINE' which stands for: Multiple Adaptive Linear Neuron model, the architecture of MADALINE is grounded on mathematical method of least squares. It was applied in telecommunications to reduce echo during phone calls regarding the ANN is almost 70 years old, it is still in commercial use. (Stanford n.d.).

Artificial intelligence is a branch of computer sciences, representing the ability of a machine to carry out intelligence related tasks.

Technology of machine learning was developed in middle 20th century, starting as AI for playing chess and checkers. Nowadays, after almost 70 years basic operation principle remains the same, yet processors computation power breakthrough made it possible to apply machine learning algorithms far beyond board games.

Machine learning is a subsection of AI, a science dedicated to methods of designing algorithms able to automatically find patterns by integrated data processing, this called training. After program or computer is trained it is able to make decisions and predictions relying on training experience, at the same time training and self-optimizing. In other words, machine learning is sort of wunderkind which only lacks learning materials, after receiving the data it figures out what to with it independently.

At the moment there are numerous training sets and algorithms. Appendix 3 represents an approximate scheme of ML.

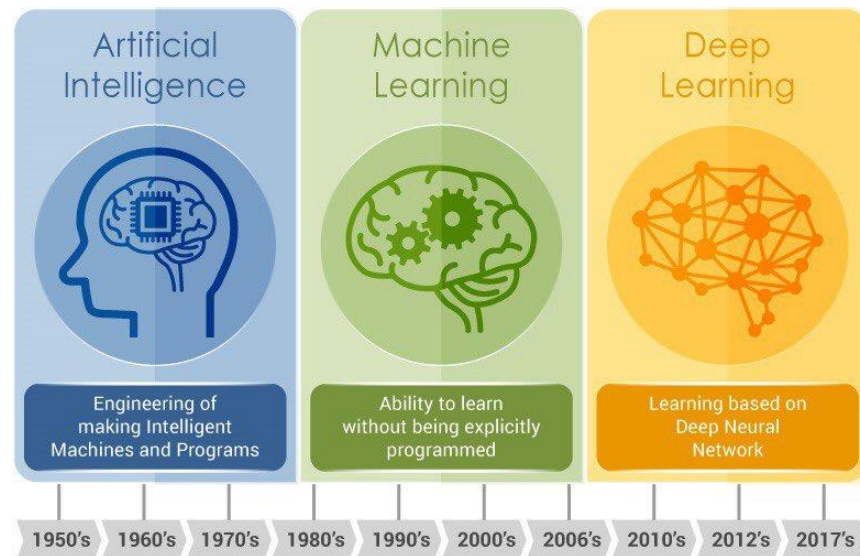


Figure 11.

Architectures of modern ANNs are not very different from MADALINE, advanced in machine learning effectiveness were achieved mostly due to breakthroughs in computation power of modern machines.

Any ANN is a set of neurons and connections between them. As shown in Figure 14 a neuron represents a simple mathematical function with many 'receive' connections with inputs x and only one 'give' connection. Each connection is assigned with weight (ω) To organize a network - neurons are grouped into layers. Neurons can receive input from previous layers, as well as send output to next layer, but never interact with other neurons from the same group.

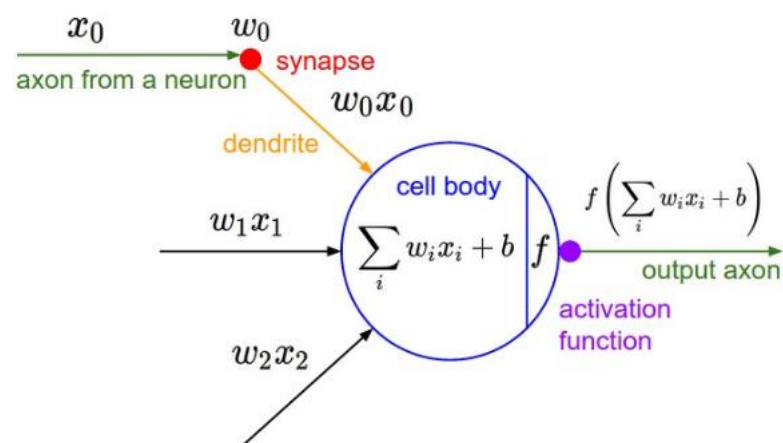


Figure 12. Mathematical model of neuron

The most basic type of ANN is single-layered neural network, like ADALINE – the predecessor of MADALINE. Even though there are two layers: input and output, input layer is ignored in layer counting, as it does not execute any calculation. Nowadays, most of neural networks architectures are

multi-layered, as they have at least one hidden layer between input and output ones. However, most considered ANNs are deep neural networks, a neural net is called deep if it has more than two hidden layers, as number of hidden layers directly affects the accuracy of a neural net.

The concept of ANN finally got mass popularization in 2010s, after surviving its last 'AI winter' (a period of reduced interest in artificial intelligence matter which entails cut of funding in research) started in 1998 as rapid increase in computation capabilities of graphics processing units (GPU) opened a wide range of areas where ANN approach of machine learning could be applied.

Since 2010 ANNs proved to be very beneficial in completely different industries. Currently, application possibilities of artificial neural networks are only limited by availability of training data sets and imagination. In Stock markets and Forex ANNs are used for trading bots and currency rate forecasts. More big companies (Alibaba, Amazon) with complex business structures are benefiting from operations optimization by ANN driven software for production machine management along with quality control and risk assessment. In medicine neural nets are helping to determine the diagnosis based on illness history or analyse scans from radiography or MRI (magnetic resonance imaging) (Fukuoka, 2002 pp. 197-228). Above mentioned examples show difference of application areas; but those applications are always specified by professionally orientated tasks. However, usage of artificial neural networks in daily routine is exorbitant. An average person interacts with ANNs at least several dozens of times per day. When making self-portrait with a smartphone - face recognition is done by a neural net. When using virtual assistants like Siri or Alexa – an ANN is responsible for voice recognition. When surfing in internet and typing a search query – suggestions are also done by a neural net bases on previous search requests.

In a past few years ANNs showed outstanding results not only in processing labelled and unlabelled data, but also in generating their own. There are examples of small projects like Mubert - a start-up which trained a neural net to generate uninterrupted stream of original music in various genres. On the other hand, there are also tech-giants like Autodesk, the biggest supplier of civil and industrial engineering software in 2018 added an ANN based option for generative design to their products (Fusion 360). Generative design means a person only needs to input general parameters like size, weight, volume etc. then Ai generates thousands of possible design variants and makes simulations to test performance properties for each variant, resulting the most optimized design solution. (Keane P. 2018). Despite of reduced man-hours for engineers and architects, the biggest advantage of generative design is that trained artificial neural network creates an algorithm which allows an Ai to modify its design decision making in the same way evolution does (Figure 15). This innovation allowed to achieve design solutions which seemed impossible,

not only in a way of appearance beyond human understanding, but also with better functioning in terms of structural efficiency and material usage.

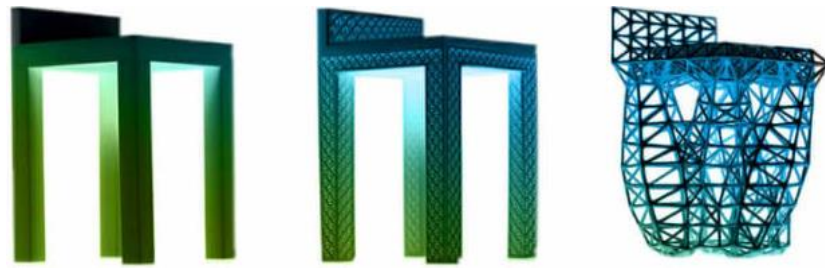


Figure 13. Traditional and generative ways of product design (Autodesk)

A vivid case study of how generative design can be applied is Airbus company – one of the biggest aircraft manufacturers. They used generative design for creating new cabin partition for their Airbus A320 plane. After generating and testing more than 10,000 options Ai created design which made new cabin partition stronger, yet 45% lighter. (Figure 16)

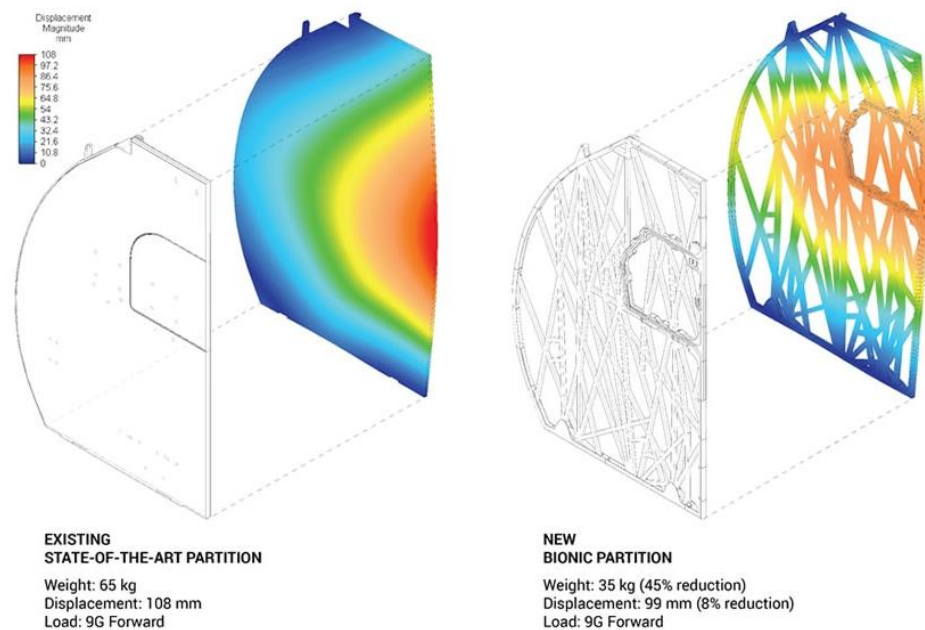


Figure 14. Stress tests comparing the existing partition to the bionic partition

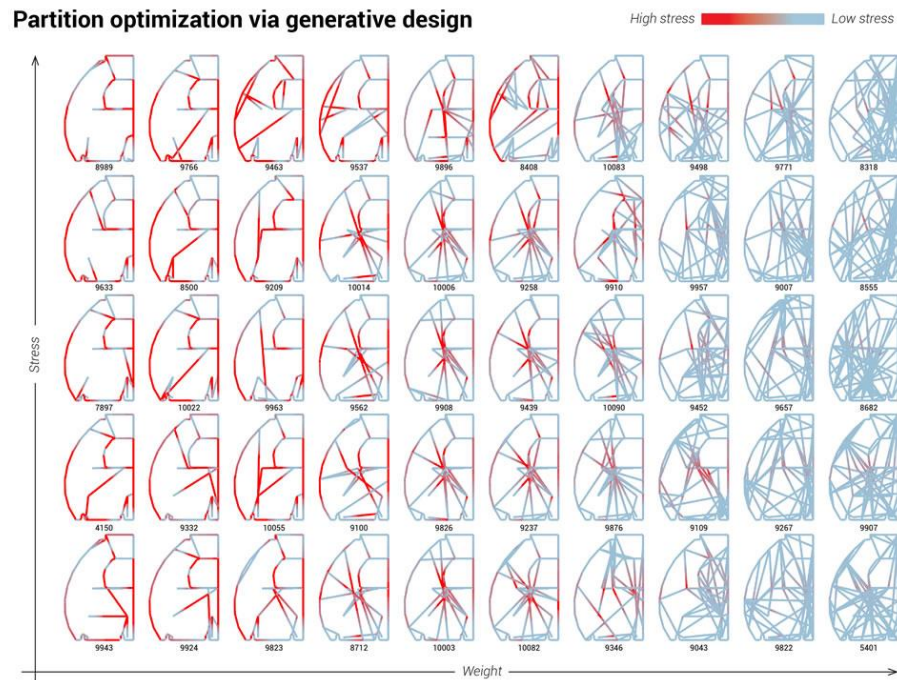


Figure 15. Optimization of design through stress tests simulation (Autodesk)

Drawing parallel to chapter 3. In spite of, this new cabin partition design has nothing to do with solid waste management sector, it precisely gives an understanding of how 4th industrial revolution benefits for both industry and ecological situation. A plane with new partitions weighs approximately half a tone less, lower weight accordingly leads to decrease in fuel consumption. In case with A320 model, one plane with new partitions saves 12,720 kg of fuel per year, in other words reduces 166,000 kg of CO₂ emissions per year. In addition, this case shows how modern technologies help to achieve smart design from perspective of materials circularity. As combination of generative design and 3D printing technology allowed improve manufacturing process by saving 95% of raw material usage. (Autodesk n.d.)

3 APPLICATIONS IN SOLID WASTE MANGMENT

This chapter focuses on case studies where mentioned above technologies or their combination were applied for commercial use. Also, basing on customers feedback - impacts of application of those technologies were evaluated.

3.1 WASTE MONITORING

Global market insights states that last year's global solid waste management market value was over 1 trillion USD. (Gupta, 2019) Where nearly half of the market is waste logistics. Every year millions of trucks transporting hundreds of millions waste containers. Primary part of waste logistics is routing for trucks, however nowadays the majority of waste transportation operations are carried out without efficient planning. Inefficient planning of routes (Figure 18) results higher occupation of personal, more fuel for trucks and create additional load on traffic in case of big cities, and most importantly causes overfilled containers.

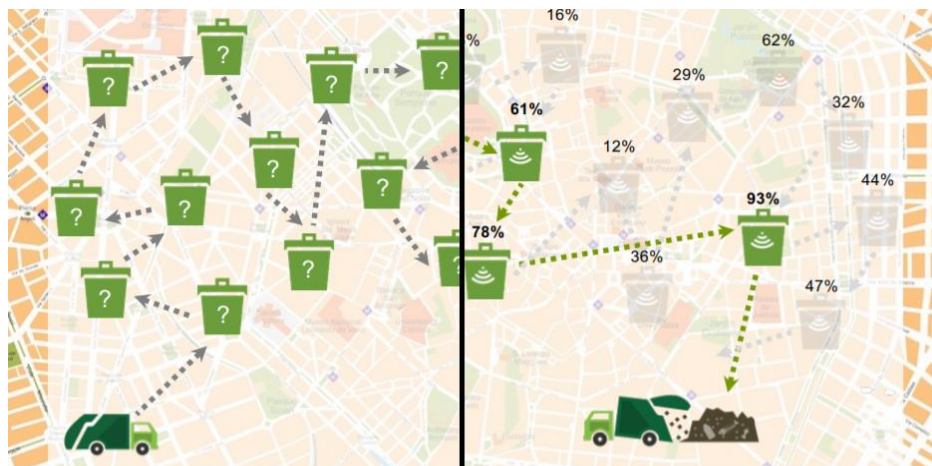


Figure 16. Comparison of traditional collection with data driven and demand-based routing model (Kekäläinen, 2016)

Enevo is a global company providing solutions for waste collection and transportation services funded in 2010 by Fredrik Kekäläinen and Johan Engström. Main component of Enevo's solution is the original, low energy consuming IoT-based sensor (Figure 19) it measures fullness rate of a waste container using the ultrasonic sonar technology. (enevo n.d.)



Figure 17. Enevo original sensor (Kekäläinen, 2016)

Combination of IoT sensors with big data cloud service and machine learning based software (Figure 20) makes it possible for customers to transparently monitor their waste generation and optimize waste logistic operations which leads to reduced costs for waste transportation and collection.

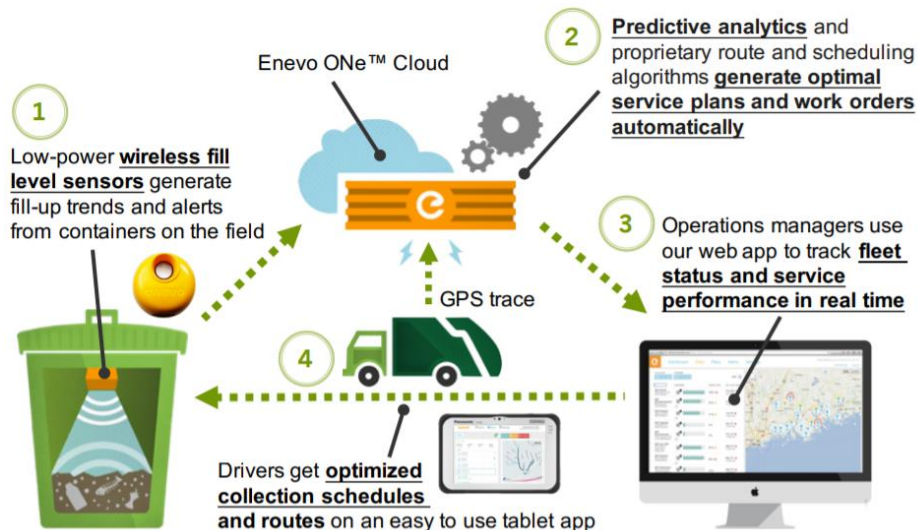


Figure 18. Enevo solution overview (Kekäläinen, 2016)

By using Enevo's solution a McDonald's franchise saved 12% from collection costs and increased recycling diversion by 50%. (Crofts, 2018)

3.2 WASTE CLASSIFICATION AND SORTING

For decades people were trying to build machines for waste sorting, until recently achievement of self-sufficiency seemed to be impossible due to inability of processes optimization or high costs. Substantially now solid waste sorting is still mostly carried out by human labor, resulting poor quality of sorting due to human-factor, at the same time causing safety issues to personnel, not mentioning that waste sorting sector to be one of the most adverse working environments.

On the contrary, Zen Robotics automated robotic waste sorters (fast and heavy pickers) cannot be affected by unpleasant environment, work autonomously and unceasingly, hourly performing up to 2000 picks just by one robot, with accuracy up to 98% for wood, plastics, inert and metal types of waste. (Appendix) Equipped with NIR, 3D, hi-res RGB camera, imaging metal detector and VIS sensors along with ZenBrain (trainable AI-based recognition software) makes it possible for robotic pickers to track objects based on their profile, color and material than automatically select

which and how object should be picked in matter of seconds. Another feature of using machine learning algorithms is ability to train AI for various types of waste and waste flows, as well as different ways of sorting. At the moment there are 17 sorting stations with Zen Robotics solutions across the globe displayed in (Figure 19), dealing mostly with construction, demolition, commercial and industrial waste types.

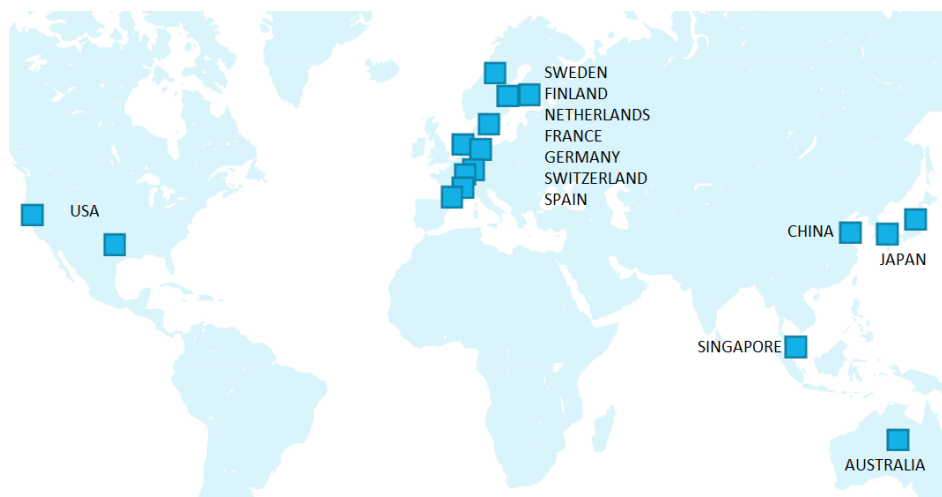


Figure 19. Global map of Zen Robotics solutions

Below displayed 2 quotations from client cases about benefits from implementation of autonomous robotic waste sorting solutions.

- Case: Remeo, Finland, Helsinki

Waste sorting station for construction and demolition types of waste.

“The plant runs virtually unmanned, with only an excavator driver doing the rough presorting on the tipping floor. A storage bunker feeds continuously the robotic sorting line, even when the excavator driver is not there. As a result, the robots produce very impressive results: the utilization of waste is already up from 70% to 90%, with the next target set at 95%.” (ZenRobotics Remeo reference n.d.)

- Case: Carl F, Sweden, Malmö

Waste sorting station for construction and demolition types of waste.

“When choosing the robots, the company’s goal was to recover up to 12,000 tons more recyclable material each year – a significant 25% increase. In addition to less waste for incineration, lower operating costs and higher income from recyclables, the company now operates a first-of-its-kind robotic waste sorting facility in Sweden.” (ZenRobotics Carl F reference n.d.)

In other references stated at Zen Robotics website it is pointed out that automated solid waste sorting solutions brought sustainability to sorting process, improved occupational safety, raised material recovery, and of course increased performance which had a positive effect on finances.

As mentioned above ZenBrain mostly focuses on determination of industrial, commercial, construction and demolition types of wastes. However, ZenRobotics are looking for new opportunities and at the moment there is a collaboration with Ferrovial about testing AI and robots on oversized MSW in Spain. Unfortunately, currently there is no information about progress available, but testing period expected to be over in July of 2020. (Ferrovial leads the 'ZRR for Municipal Waste' project to apply robotics in processing municipal waste n.d.)

It is possible there was no significant progress. Same reasons for absence of any commercial autonomous municipal solid waste sorting solutions – complexity of waste flow and diversity of waste elements in MSW. Difference is shown in the Figure below.

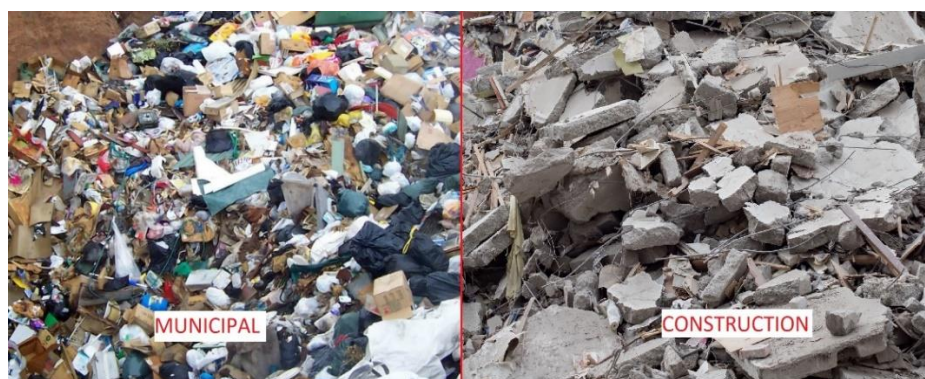


Figure 20. Comparison of contents in waste types.

4 IMPACTS AND CHALLENGES

This chapter is based on results of mentioned below survey and reflections of author.

ISWA (International Solid Waste Association) is a worldwide leading independent waste management association. It operates in 93 countries, creating the biggest network aimed for collecting and sharing relevant knowledge and experience related to sustainable waste management. As a part of its mission, ISWA studies and promotes innovations which could be beneficial for SWM sector. Phenomenon of 4th Industrial Revolution is a complex of such innovations, thereby a global survey named “The Impact of the 4th Industrial Revolution on the Waste Management Sector” was presented on ISWA World Congress 2017.

The survey was lasted more than half a year and involved 1087 respondents from 97 countries. All of the respondents are working in various areas of waste management industry, majorly in private sector, as

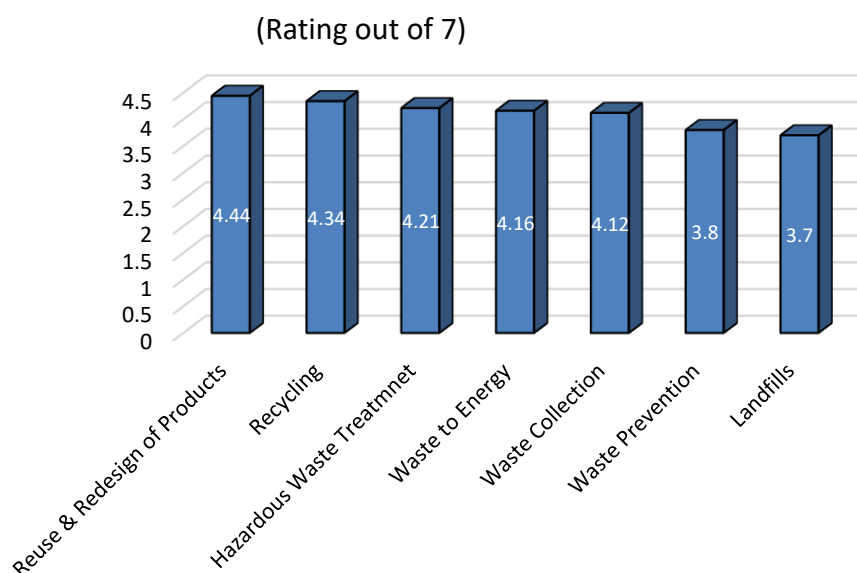
well as most of interviewed are holding management positions. The specifications of the survey are represented in Appendix 5. Thus, the survey can be justifiably considered as a relation of Waste Management community to the Industry 4.0 topic.

4.1 IMPACTS

According to the survey 97% interviewees believed that changes brought by fourth industrial revolution will impact the waste sector in general, where 50% consider this impact by 2030 to be “major” and 45% as “some”.

On this basis participants were asked what the most affected areas would be. Results are displayed in the (Chart 1), representing rating of 7 waste-related areas. Clearly reuse, recycling, as well as new ecodesign concepts and standards for products are on the lead positions as fourth industrial revolution is in strong bonds with circular economy, as it was mentioned earlier - circular economy for resources is achievable with tools brought by Industry 4.0 e.g. digital manufacturing or advanced ERP's. On the other hand, waste prevention expected to have lower impact than waste to energy for instance, while on the contrary those two have inverse potential to achieve sustainability in waste traffic.

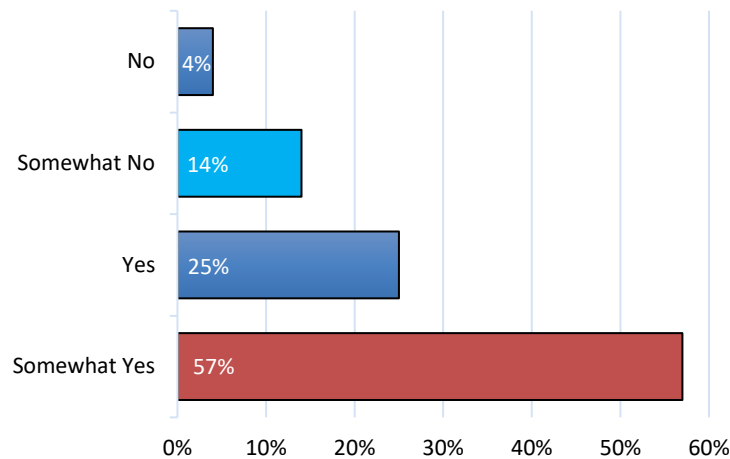
Areas most impacted by the 4th Industrial Revolution. (Mavropoulos, 2017, p. 19)



It is also attested by (Chart 3) describing response percentage to achievements which will happen before 2030. Similar to previous chart the top is held by innovations aimed to improve use of resources.

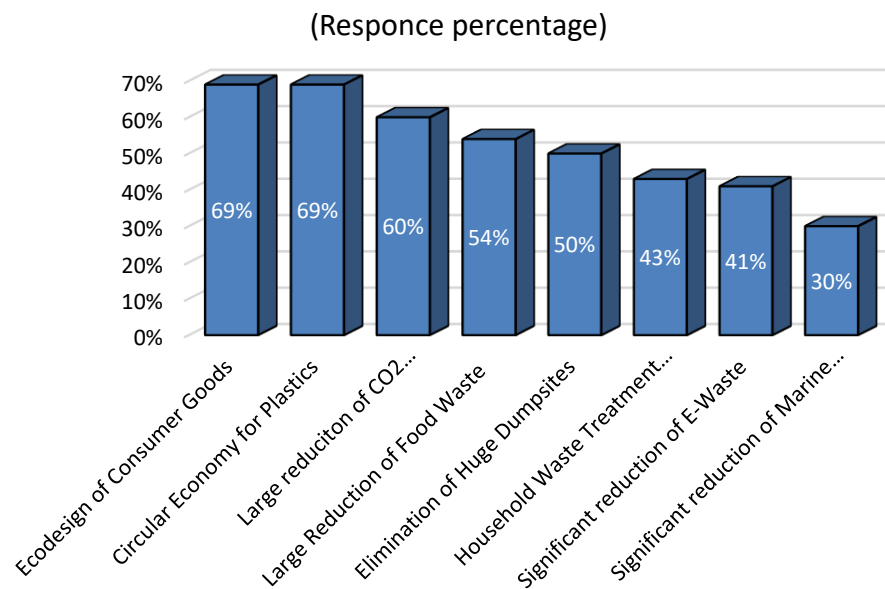
On the other hand, when survey participants were asked if fourth industrial revolution will result circular economy for most of consumer goods, answers displayed in Chart 2 were generally positive, yet only a quarter answered with a solid 'yes'.

How much do you know about 4th industrial revolution? (Mavropoulos, 2017, p. 7)



It turns out even recycling and waste-related industry experts who acquainted with Industry 4.0, do not completely find the interconnectivity with circular economy.

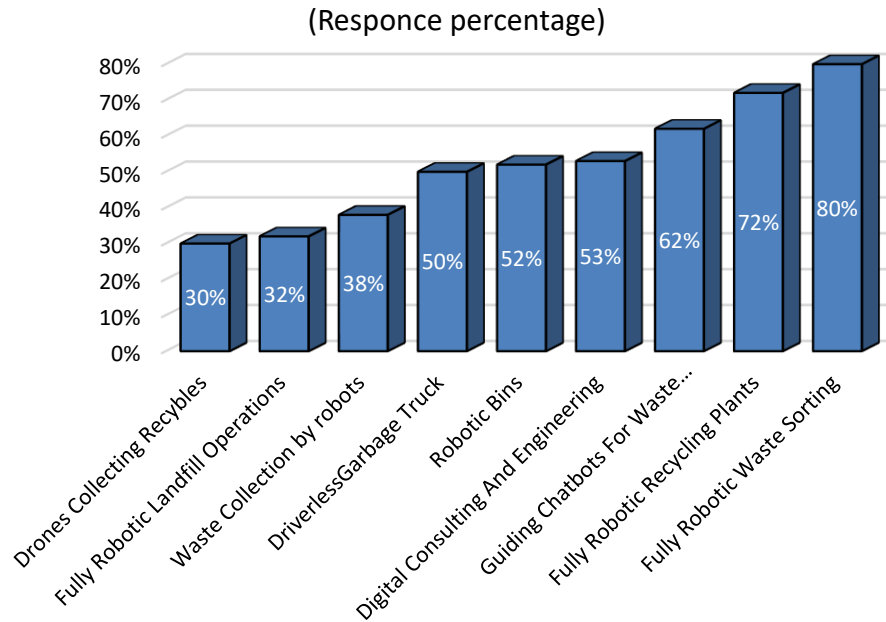
Developments that will happen before 2030



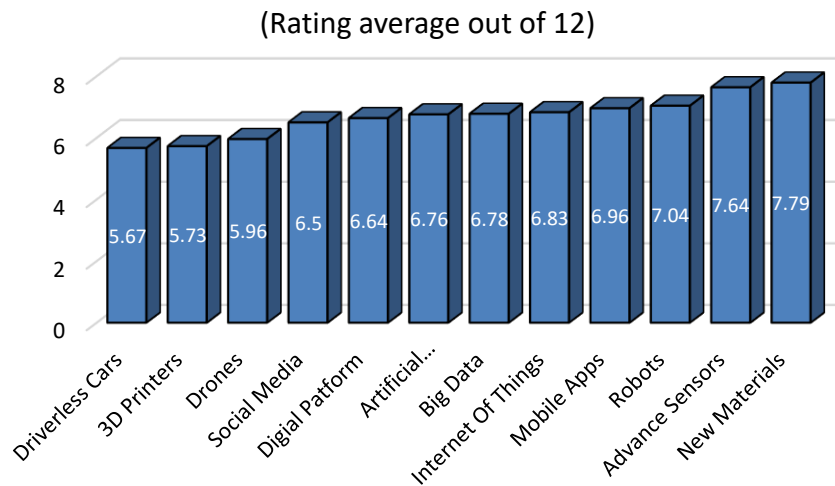
As for forecasting, we can say: for now, predictions are quite accurate, because today's tendencies of development are very similar to top positions from the rating presented in (Chart 4), like previous chart it also displays response percentage, but this time for innovations to be available in 2030. Later in this paper Referring to chapter 3.4 where I was focusing

on cases of automated robotics merged with waste sorting and recycling operations.

Innovation available in 2032



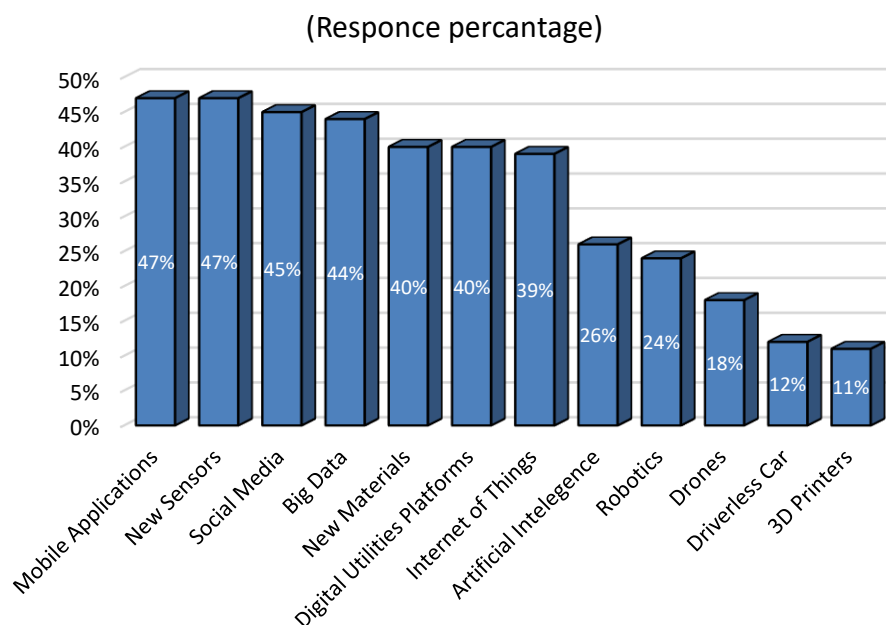
Expected impact by 2032



Another thing worth mentioning is weird dissonance in answers (excluding new sensors) for investments question (Chart 5). While highlighting importance or impacts of actual waste management solutions, participants surprisingly ranked mobile applications to be the first and social media the third important areas for investments. As digital utilities platforms are in the middle of rating, I assume getting society with familiar waste issues and providing guidelines is implied. However, taking into account importance of mentioned above things can't be neglected - it is

evident that areas of wider application: (new materials, big data, internet of things, artificial intelligence, robots and even 3d printers which took last place) would result much greater impact, by being able to affect both people and businesses. This desire of investing basically into promotion remains obscure at least by two reasons. Firstly, both social media and mobile applications do not require much investments in comparison to other areas. Secondly, throw out the years these two proved to have miserable effect on waste management and recycling sectors. It is irrefutably easier to promote the importance of change, rather than making a change. It might be acceptable before, today having all the potential of new technologies I would consider such investment priority as erroneous, a waste of money.

Preferred areas for investment.



To sum up, it seems that rate of changes approach, as well their scale brought by of the 4th Industrial Revolution, are rather underestimated. A deeper study in benefits and risk assessments of implementation Industry's 4.0 tools in waste industry are urgent, as only 150 out 1087 participants consider themselves knowledgeable of 4th industrial revolution.

In addition to conclusions made from ISWA's survey there also environmental, socio-economic impacts workplace impacts.

Environmental impact:

Increasing speed and quality of operations in MSWM by Machine Learning and Neural Networks will help in sorting and recycling permanently growing municipal waste streams. Making it possible for certain materials to be reused in product manufacturing.

Another big step towards circularity of materials is applying IoT-based sensors on a mass scale, this will allow to track entire lifespan from a product to waste and collect data on every stage of lifecycle. Using this data an optimized eco-friendly design can be developed and further improved with upcoming data. The bigger influence of circular economy – the less waste ends up in open dumps, landfills, and energy recovery plants.

Socio-economic impact:

Implementation of technologies related to 4th Industrial revolution will have massive impact on both financial aspects and life quality. Circular economy for materials will allow to decrease expenses from raw material extraction, transportation, and processing. Also, requirements of modern tools are mostly based on providing computational equipment and access to internet. Such high accessibility of technologies allows 4th Industrial Revolution to uniformly affect municipal waste management sectors of both developed and developing countries. As well as, create highly competitive market of waste monitoring and processing solution, because implementation of IT-based solutions are not heavily dependent on financial state of a company or waste industry as a whole.

Labor market impact:

Vice President of International Solid Waste Management Association Carlos Silva Filho claims that companies relying on traditional business models will not be able to compete in the market by 2032. (Mavropoulos, 2017 p. 5). This statement can be related to one of the integral consequences brought by any technological revolution; a company or an industry can develop sustainably only if it is able to adapt to global changes. Innovations and new technologies always make some jobs irrelevant resulting disappearance of professions or even industries. On the other hand, any innovation always leads new business opportunities which eventually result creation of new professions requiring higher qualification, as well as new more complex industries. For instance, use of Ai and robotics may turn waste sorting stations into almost fully automated facilities accordingly minimizing amount of human labor in this area.

5 CONCLUSION

Innovations associated with 4th industrial revolution are already showing great results in improving all manner of industries. Taking into account the scale of changes, it can be assumed that society is at the transitional stage between technological eras. Furthermore, as majority of those improvements are related to optimization and efficient planning of existing processes – there is a big chance of shifting from linear economy

to a circular one. In other words, using full potential of raw materials lifecycle.

Throughout this paper technical specifications of technologies with highest impact potential (Internet of Things, Big Data and Artificial Neural Networks) were studied. In addition, cases of applications in Solid Waste Management (waste Sorting and waste Monitoring) were reviewed, as well as impacts to brought by mentioned above technologies were evaluated; use of IoT sensors along with Big Data resulted reduced waste transportation costs and improved overall efficiency of waste collection, and an Artificial Neural Network 'learned' how to identify certain types of waste allowing to create an automated waste sorting station which outperforms traditional waste sorting stations.

In conclusion, it is clear that technologies associated with 4th industrial revolution are very perspective in in achieving wasteless future and improving solid waste management sector in particular. However, at this point the implementation of such technologies in SWM has more individual character rather than mass application. Thus, there is a need in deeper research of areas related to Industry 4.0, as well as promotion of technologies reviewed in this paper at the legislative level.

REFERENCES

- Akst, J. (2019). A brief history of AI, machine learning, artificial neural networks, and deep learning. Retrieved January 16, 2020 from <https://www.the-scientist.com/magazine-issue/artificial-intelligence-versus-neural-networks-65802>
- Autodesk. (2020). Reimagining the future of air travel. Retrieved March 13, 2020 from <https://www.autodesk.com/customer-stories/airbus>
- Clifford, L. (2008). How do your data grow? *Nature* 455, 28–29 Retrieved January 14, 2020 from <https://doi.org/10.1038/455028a>
- Culurciello, E. (2017). “*Neural Network Architectures*”. Retrieved January 22, 2020 from <https://towardsdatascience.com/neural-network-architectures-156e5bad51ba>
- Crofts, A. (2018). How we saved McDonald's 12%. Retrieved February 16, 2020 from <https://www.enevo.com/blog/how-we-saved-mcdonalds-12-44>
- Columbus, L. (2017). *53% Of Companies Are Adopting Big Data Analytics*. Retrieved January 2, 2020 from <https://www.forbes.com/sites/louiscolombus/2017/12/24/53-of-companies-are-adopting-big-data-analytics/#2784633e39a1>
- Diana Celaj, Josh Desmond, Akshaye Shah and Sola Shirai (2017) *Preparing for the Use of Big Data in Denmark’s Waste Management Sector* p 17-19. Retrieved January 20, 2020 from https://web.wpi.edu/Pubs/E-project/Available/E-project-101217-041523/unrestricted/Big-Data_Final_Report.pdf
- Dimaano, F. (2019) What is Machine Learning? Retrieved April 6, 2020 from <https://towardsdatascience.com/what-is-machine-learning-885aa35db58b>
- David Reinsel, John Gantz and John Rydning (2018) “*The Digitization of the World From Edge to Core*” Retrieved January 22, 2020 from <https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf>

European Commission. (2020). *A new Circular Economy Plan for a cleaner and more competitive Europe*, p. 3. Retrieved May 6, 2020 from <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN>

Ferrovial (n.d.) Ferrovial leads the 'ZRR for Municipal Waste' project to apply robotics in processing municipal waste. Retrieved May 22, 2019 from https://www.ferrovialservicesna.com/news_article/ferrovial-leads-the-zrr-for-municipal-waste-project-to-apply-robotics-in-processing-municipal-waste/

Fuu Yun Chee (2020) “Exclusive: Europe wants single data market to break U.S. tech giants' dominance” Retrieved January 22, 2020 from <https://www.reuters.com/article/us-eu-data-exclusive-idUSKBN1ZS32E?taid=5e3220d0ebed6f0001a56fb7>

Fukuoka Y. (2002). *Artificial Neural Networks in Medical Diagnosis*. In: Schmitt M., Teodorescu HN., Jain A., Jain A., Jain S., Jain L.C. (eds) *Computational Intelligence Processing in Medical Diagnosis. Studies in Fuzziness and Soft Computing*, vol 96. Physica, Heidelberg. Retrieved March 13, from https://doi.org/10.1007/978-3-7908-1788-1_8

Gupta, A. & Paranjape, N. (2020). *Solid Waste Management Market Size By Waste (Municipal Solid Waste {Residential, Commercial [Hospitals, Offices & Institutions, Hotels, Others]}, Industrial Solid Waste{Equipment Manufacturing, Mining, Food Processing & Textiles, Others}), By Treatment (Open Dumping, Disposal {Landfill, Recycling, Incineration/Combustion, Composting & AD}), By Material (Paper & Paperboard, Metals, Plastics, Food, Textiles, Others), Industry Analysis Report, Regional Outlook, Competitive Market Share & Forecast, 2020 – 2026*. Retrieved February 10, 2020 from <https://www.gminsights.com/industry-analysis/solid-waste-management-market>

Hardesty, L. (2017). *Explained: Neural networks*. MIT News Office. Retrieved May 22, 2019 from <http://news.mit.edu/2017/explained-neural-networks-deep-learning-0414>

Hosseini Shahrokni, Bram Van der Heijde, David Lazarevic, Nils Brandt (2014) *Big Data GIS Analytics Towards Efficient Waste Management in Stockholm*. Retrieved January 22, 2020 from <https://doi.org/10.2991/ict4s-14.2014.17>

Inzaugarat, E. (2018). Understanding Neural Networks: What, How and Why? Retrieved May 22, 2019 from <https://towardsdatascience.com/understanding-neural-networks-what-how-and-why-18ec703ebd31>

Keane, P. (2018). Generative Design comes to Fusion 360. Retrieved April 23, 2020 from <https://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/16862/Generative-Design-Comes-to-Fusion-360.aspx>

Kuznig, R. (2020). Is a world without trash possible? National Geographic. Retrieved April 13, 2020 from <https://www.nationalgeographic.com/magazine/2020/03/how-a-circular-economy-could-save-the-world-feature/>

Karasev, P. (2020) “Как искусственный интеллект помогает перерабатывать отходы” Retrieved April 5, 2020 from <https://www.rbc.ru/trends/green/5d6566149a79476b67a9c20c>

Kekäläinen, F. (2017). IoT & Big Data Solving Problems For The Waste & Recycling Industry. Retrieved February 16, 2020 from https://www.europarl.europa.eu/cmsdata/103427/4_enevo.pdf

Lasse Lueth, K. (2014). Why the Internet of Things is called Internet of Things: Definition, history, disambiguation. Retrieved March 13, 2020 from <https://iot-analytics.com/internet-of-things-definition/>

LeCun, Yann, et al. (1998). “Gradient-based learning applied to document recognition.” Proceedings of the IEEE 86.11 (1998): 2278-2324. Retrieved January 25, 2020 from <http://yann.lecun.com/exdb/publis/pdf/lecun-98.pdf>

Mavropoulos, A. (2017). “Impacts of 4th Industrial Revolution on the Waste Management”. Retrieved April 6, 2020 from https://www.iswa.org/media/publications/knowledge-base/?tx_iswaknowledgebase_searchbox%5Bsearchphrase%5D=the%20impact%20of%20the%204th%20industrial%20revolution%20&cHash=1199ed8b7a6fe6a79efade304f44b498

Oracle. (n.d.) What is IoT? Retrieved February 6, 2020 from <https://www.oracle.com/internet-of-things/what-is-iot.html>

Postscapes. (2019). Internet of Things (IoT) History. Retrieved May 6, 2020 from <https://www.postscapes.com/iot-history/>

Quindazzi, M. (2020). 24 Industries impacted by Ai. Retrieved April 20, 2020 from <https://twitter.com/osmanabdAllah92/status/1244261494457581571>

Reinsel, D., Gantz, J., Rydning, J., (2018). The Digitalization of the world. Retrieved December 6, 2019 from <https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf>

Sanderson, G. (2019). But what is a Neural Network? | Deep learning, chapter 1. Retrieved February 6, 2020 from <https://www.youtube.com/watch?v=aircAruvnKk>

Sanderson, G. (2019). Gradient descent, how neural networks learn | Deep learning, chapter 2. Retrieved February 6, 2020 from <https://www.youtube.com/watch?v=IHZwWFHwA-w&t=715s>

Stanford (2006). Neural Networks History: The 1940's to the 1970's. Retrieved April 23, 2020 from <https://cs.stanford.edu/people/eroberts/courses/soco/projects/neural-networks/History/history1.html>

United Nations. (2019). UN Report: Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating'. Retrieved January 22, 2020 from <https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/>

Van Veen, F. & Leijnen, S. (2019). "The Neural Network Zoo". Retrieved January 11, 2020 from <https://www.asimovinstitute.org/neural-network-zoo/>

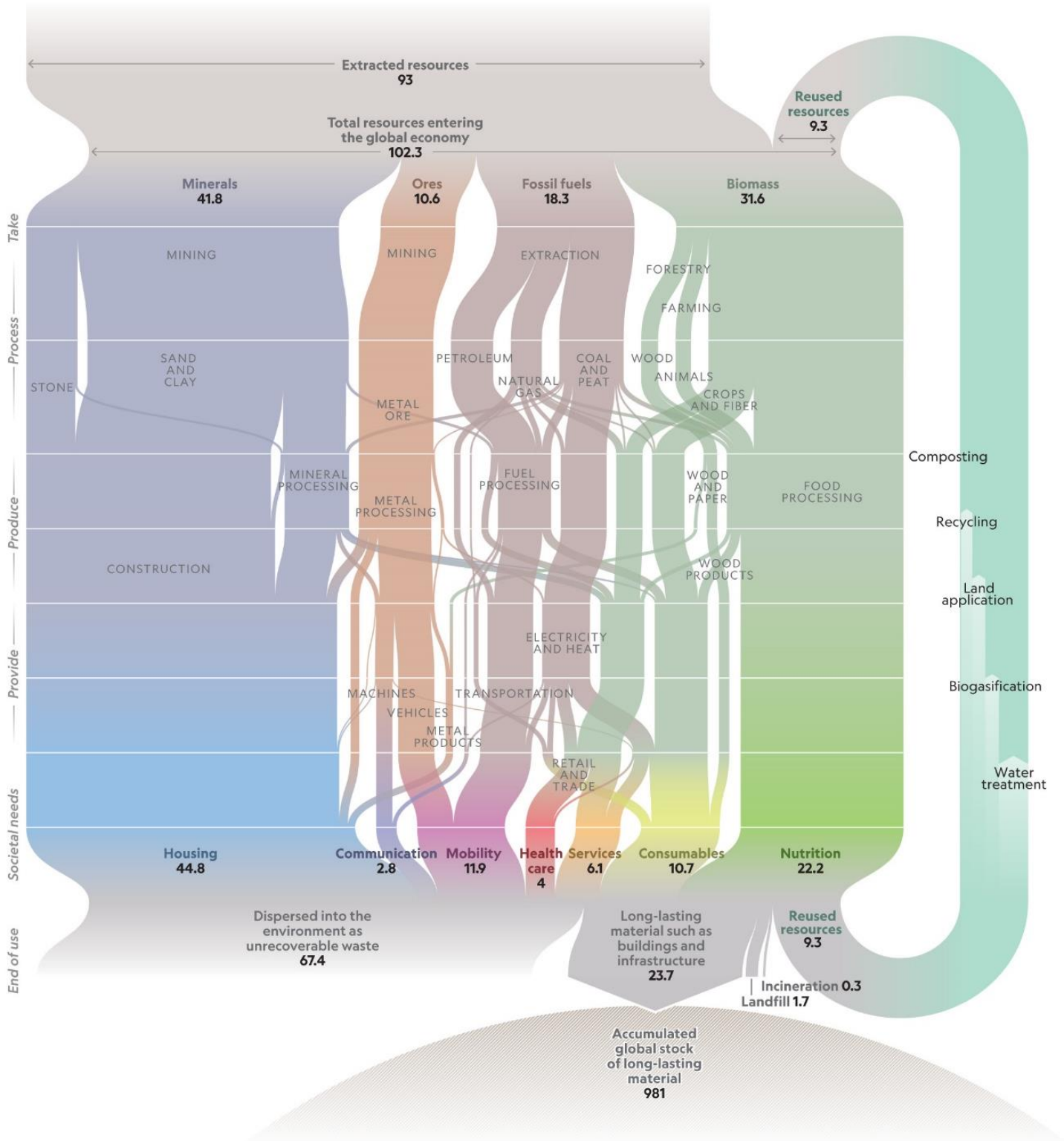
Xinwen, H., Cheng-Lin, L. & Tieniu, T. (2006) "*Learning Boosted Asymmetric Classifiers for Object Detection*" 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06), New York, NY, USA, 2006, pp. 330-338. Retrieved June 3, 2019 from <https://doi.org/10.1109/CVPR.2006.166>

ZenRobotics (n.d.). Intelligence with Zenbrain. Retrieved March 13, 2020 <https://zenrobotics.com/solutions/intelligence-with-zenbrain/>

APPENDICIES

Appendix 1

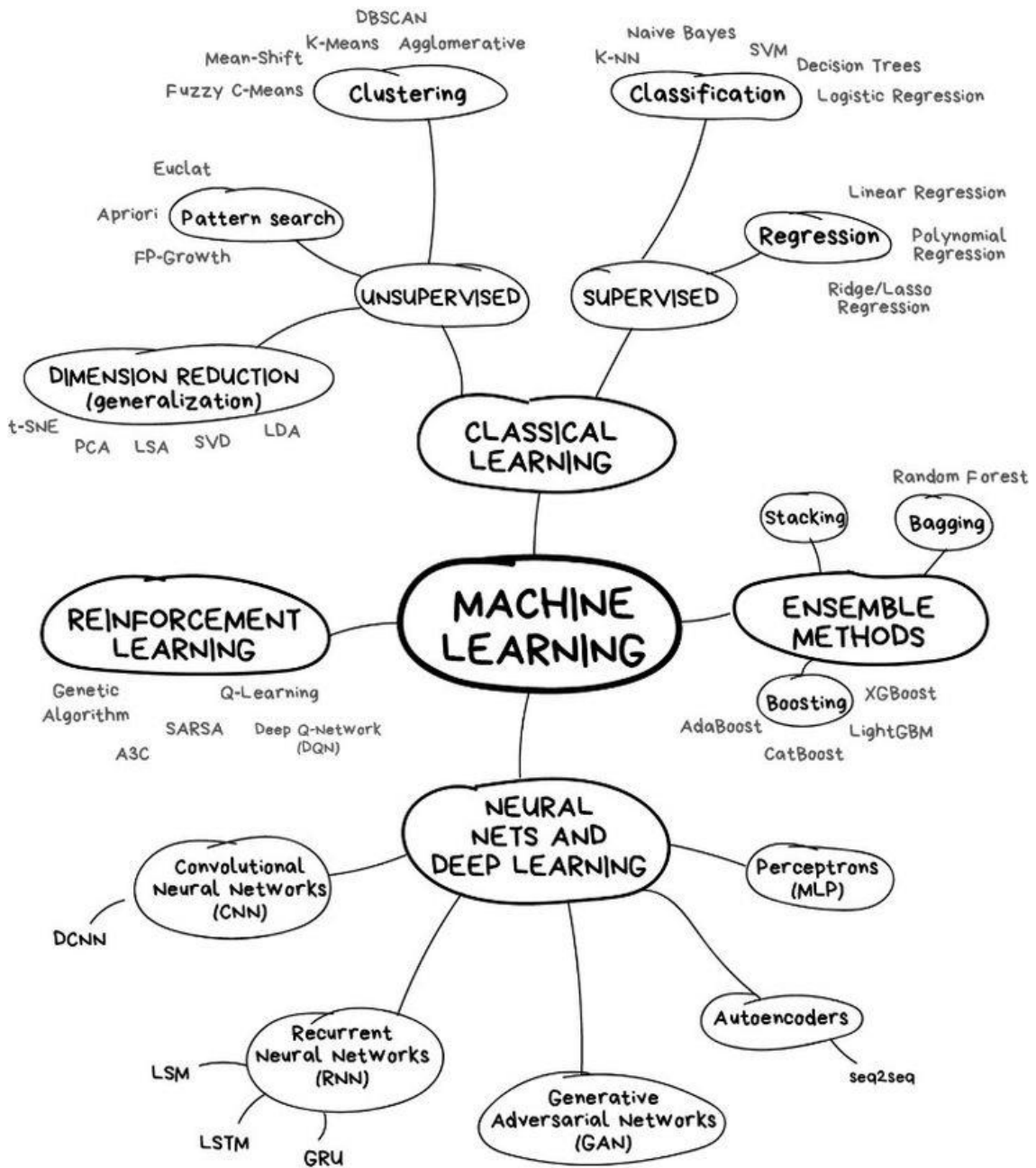
AN X-RAY OF THE GLOBAL ECONOMY. (Kuznig, 2020).



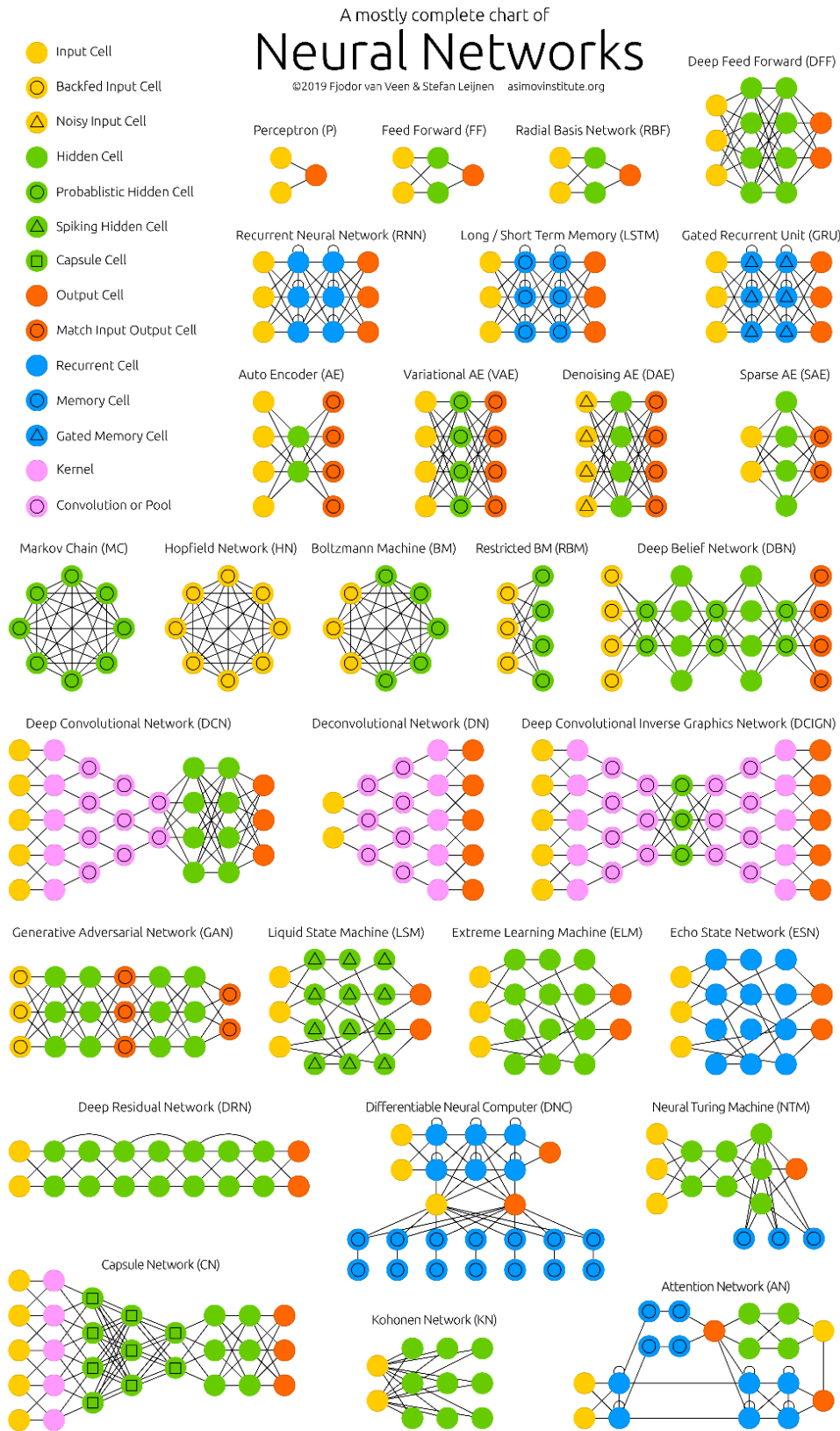
24 INDUSTRIES IMPACTED BY AI (Quindazzi, 2020)



WHAT IS MACHINE LEARNING? (Dimaano, 2019)



THE NEURAL NETWORK ZOO (Van Veen, 2016)



ROBOTIC SORTING STATION INFOGRAPHIC (ZenRobotics, n.d.)



ZENROBOTICS Recycler – robotic sorting station

ZenRobotics Recycler (ZRR) reclaims valuable raw materials from waste with the help of robots and advanced machine learning technology.
→ www.zenrobotics.com

The Robotic Sorting Station enables fully automated waste sorting. The simple process can be installed in a compact space with little additional equipment. There's no need for shredding as the system can handle large objects up to 20 kg!

SCREENING
A screen divides the waste into fines, a light fraction and a 3D fraction which continues its way to the ZenRobotics Recycler.

Low Operating Cost
10 kW

24 h/day



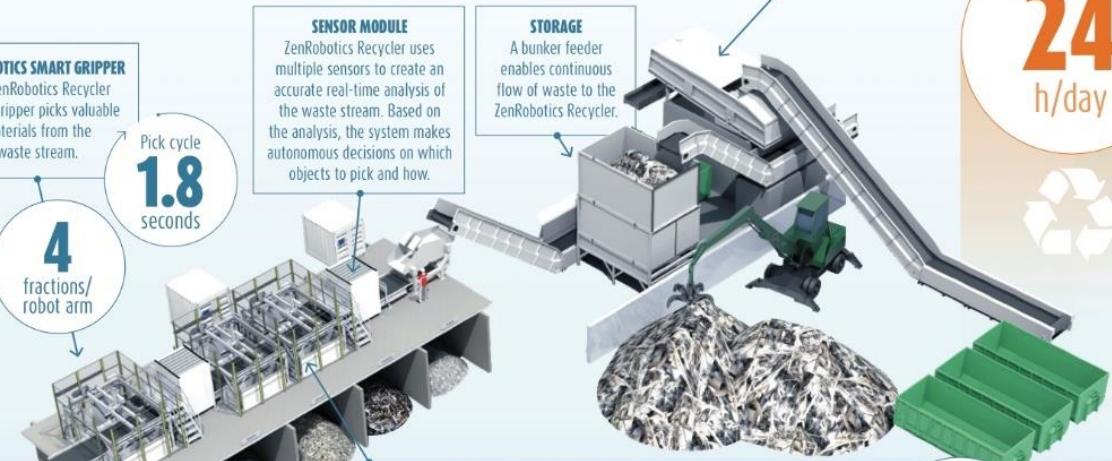
ZENROBOTICS SMART GRIPPER
The ZenRobotics Recycler Smart Gripper picks valuable materials from the waste stream.

Pick cycle
1.8 seconds

4 fractions/robot arm

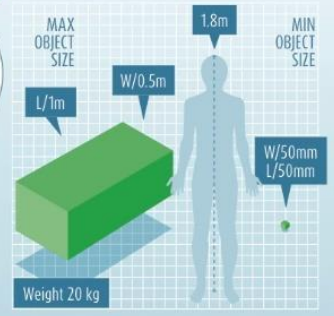
SENSOR MODULE
ZenRobotics Recycler uses multiple sensors to create an accurate real-time analysis of the waste stream. Based on the analysis, the system makes autonomous decisions on which objects to pick and how.

STORAGE
A bunker feeder enables continuous flow of waste to the ZenRobotics Recycler.



MAX PICKING SPEED
2000 PICKS/H/ROBOT
4-8 t/h throughput

SORT LARGE AND SMALL FRACTIONS



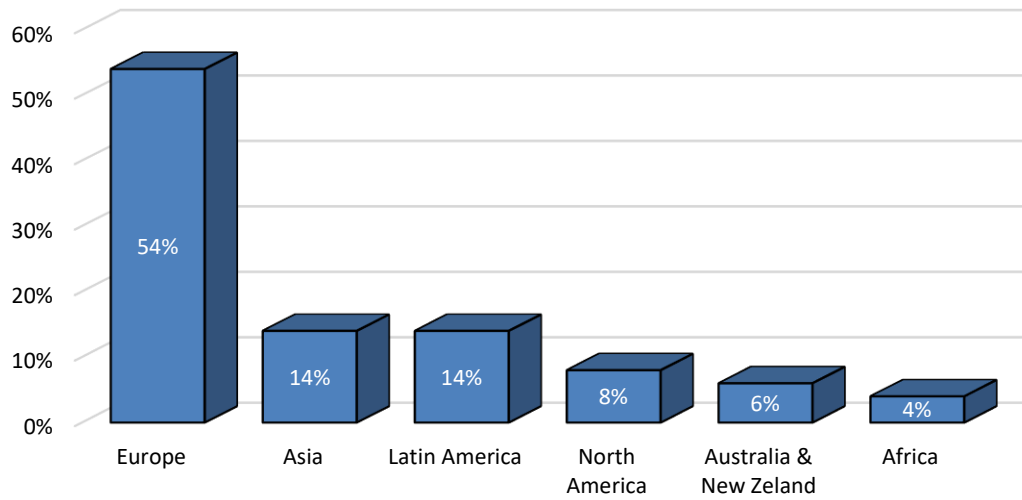
Up to **98%** purity



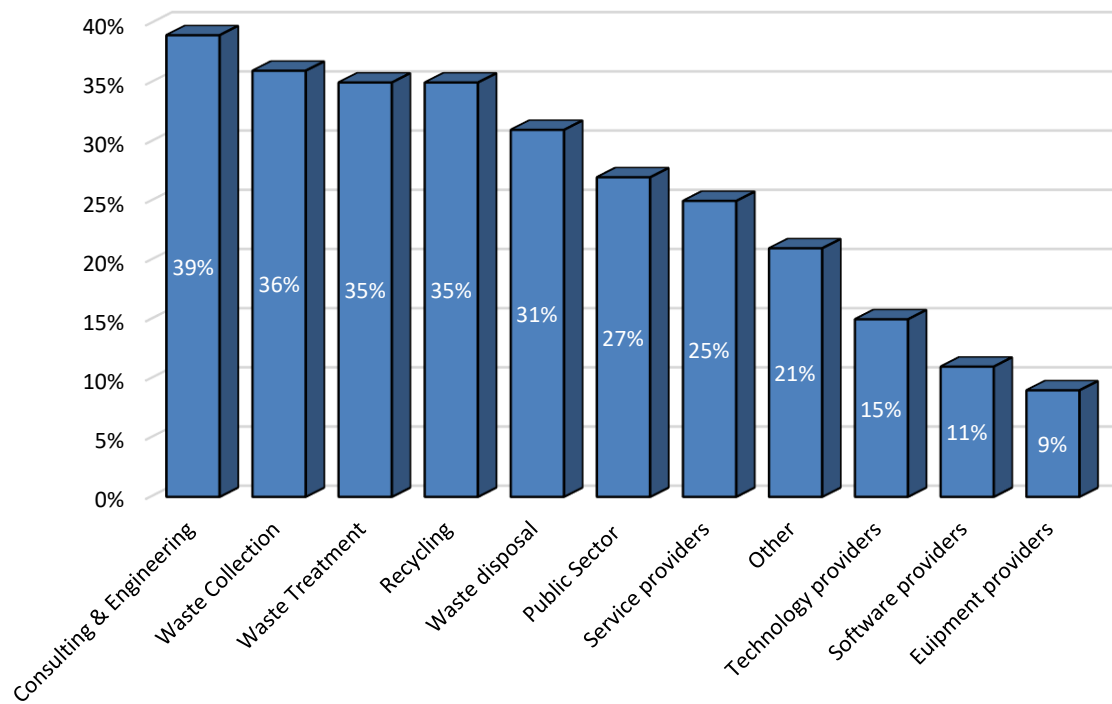
HIGH QUALITY FRACTIONS
The system can pick various qualities of inert and wood fractions as well as mixed rigid plastics and metals. The ZRR can simultaneously pick multiple fractions from mixed C&D and C&I waste streams.

INFORMATION ABOUT PARTICIPANTS OF “THE IMPACT OF THE 4TH INDUSTRIAL REVOLUTION ON THE WASTE MANAGEMENT SECTOR” SURVEY.

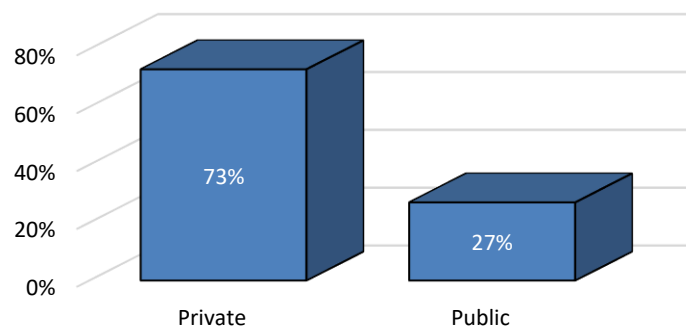
Region.



Area(s) of company/organization.



Business sector.



Held positions.

