Resource Efficient Use of Mixed Wastes

Case study: ZenRobotics Recycler – Robotic waste sorting

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Key findings

ZenRobotics Recycler, Robotic Waste Sorting

Context

ZenRobotics Ltd, a Finnish SME established in 2007, has developed a robotic waste sorting system. ZenRobotics Recycler (ZRR) has the potential to bring a new innovative concept in waste sorting, replacing low-performing hazardous manual jobs with highly efficient and fast autonomous robotic pickers. The key innovation of ZRR is a unique machine-learning based system, which gathers gigabytes of data of its environment, makes smart decisions and moves a robot arm in an unpredictable environment.

Locations of implemented ZRR

Objectives

ZenRobotics aims to improve waste sorting with highly efficient and fast autonomous robotic pickers. Designed to lower the cost of recycling, the ZRR defines Next Generation Recycling. The increasing demand for smart waste sorting services and technologies provide a major market opportunity for technology providers. Adoption of new technology and regulatory pressure can create a market far bigger than the existing one.

Key figures

Max. Picking Speed	2000 picks/hour (one robot arm)
Max. Object Weight	20kg
Max. Object Size Min. Object Size	W 500 mm, L 1000 mm W 50 mm, L 50 mm
Recovery rate	< 95%
Purity of End Fraction	< 98%

Description

Currently ZRR can sort mixed solid waste streams like construction and demolition waste (C&D) and commercial and industrial waste (C&I). ZenRobotics, with about 30 employees, has already raised €17 million in equity investments and its C&D ZRR has won several reputable cleantech awards.

In 2013 ZenRobotics and SUEZ environnement signed a Global Frame Agreement on the delivery of ZRR waste sorting systems. The world's first robotic sorting station that's designed around the robots was installed at a SUEZ Finland site in Helsinki in 2014. Today, ZenRobotics Recycler waste sorting systems are sold to the Netherlands, Switzerland, Japan, France & USA.

Key factors of success and potential for replicability

The ZenRobtics Recycler enables unprecedented flexibility to waste sorting. The customer can adjust the sorting task whenever incoming waste varies.

The ZRR system doesn't degrade as software-based technologies can be continuously upgraded with new features. The learning system can be installed in various markets with different kind of waste. Over time it will recognise more waste types which can be provided to other customers as upgrades.

Conclusion

Customer 1: “We have been able to increase the recovery rate from 70% to 90%. After all, it’s about increasing efficiency.”

Customer 2: “We were looking for alternative ways to reduce our dependency on manual sorting for the years to come as finding people who are willing as well as skilled was becoming harder every year. Also, the ZRR brings endurance and speed a human can’t deliver.”

“We believe that robotic sorting will lower our costs, while continuity will increase.”

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Useful link

- *https://www.youtube.com/watch?v=X_1sOPqM_VA*
- *https://www.youtube.com/watch?v=z1gO6Qsb6tQ*
- *https://www.youtube.com/watch?v=RsnVm063Zfs*

1. Introduction

ZenRobotics Oy, a Finnish SME established in 2007, has developed a robotic waste sorting system ZenRobotics Recycler (ZRR).

Currently ZRR can sort mixed solid waste streams like construction and demolition waste (C&D) and commercial & industrial waste (C&I). The system can also be taught to sort specific objects like plastic bags by color, allowing more versatile sorting tasks.

Designed to lower the cost of recycling, ZRR has the potential to improve waste sorting, replacing low-performing traditional techniques and hazardous manual jobs with highly efficient and fast autonomous robotic pickers. The system relies on machine learning technology in both classifying the valuable raw materials in the waste stream, and in controlling the robot's adaptive picking motions.

Figure 1: ZenRobotics Recycler sorting C&D waste

1.1. Context of the initiative

The increasing scarcity for raw materials, growingly strict regulations (European Waste Framework Directive & Landfill tax escalation) and social pressure have turned waste into a resource, making recycling highly attractive. Waste management companies need more efficient technologies that achieve the highest purity of recovered material, reducing the contamination of the sorted waste while also reducing the losses.

High initial investment required for setting up innovative facilities is a major barrier for waste management companies. Despite the increasing utilisation of automation in the facilities (drums, conveyor belts, etc.), manual labour is still required to guarantee a good quality of sorting materials. The health hazards of the job and low salaries make it difficult to attract reliable work force and, therefore, the need for sustainable waste management drives adoptions of smart sorting services and technologies, providing a major market opportunity for technology providers.

1.2. Objectives

ZenRobotics aims to bring a new concept in waste sorting with highly efficient and fast autonomous robotic pickers. Designed to lower the cost of recycling, the ZRR defines Next Generation Recycling. The increasing demand for smart waste sorting services and technologies provide a major market opportunity for technology providers. Adoption of new technology and regulatory pressure can create a market far bigger than the existing one.

1.3. Results

Sensor fusion and real-time robot control

ZenRobotics has succeeded in bringing robots to work in the demanding waste management environment – an environment far too complex for standard robot control systems. Traditional industrial robotics solves problems where the environment is predictable, objects are always where they are supposed to be, collisions are always exceptions and identical movement paths are repeated over and over again.

The key innovation is a unique system, which gathers gigabytes of data of its environment, makes smart decisions and moves a robot arm in an unpredictable environment. The core of ZenRobotics' sensing technology is sensor fusion. The ZRR system 'combines' sensors by processing the information from simple physical sensors into a complex virtual sensing solution. The ZRR can, for example, tell apart various objects and classify them into different fractions, a task that is simple for humans, but remarkably difficult for typical automation systems.

The control system must adapt to the situation in near real-time, and react accordingly. The challenge is not only in the correct recognition of the objects, but also in deciding how exactly the object is best approached by the gripping arm to avoid collisions with other objects while the belt is moving, what is the best point to grasp for lifting, and how to manipulate oblong objects into the fraction throw chutes.

Figure 2: ZenRobotics Recycler, ZRR2. Sensor module & two robots

Manipulation

For manipulation, ZenRobotics has developed in-house gantry-type robot arm that has proven capability to sort C&D waste and can be extended to be used for other waste streams, for example C&I. The robot overcomes the problems with industrial robots providing real-time control possibility and therefore enabling speed and reliability.

One ZRR arm can pick up to 2000 picks/hour. A typical ZRR system with two robot arms make up to 4000 picks/hour. The gantry type robot is integrated into the ZRR Smart Gripper, which has been developed to pick objects from a waste stream. The gripper is designed to handle objects that are odd-form: not regular in shape, or in their point of balance, or they may be heavy, wet, frozen, or dirty. The maximum load is up to 20kg. However, depending on the waste stream, fractions often weigh between 0.5-2kg in average.

Figure 3: ZenRobotics Smart Gripper™

Table 1: ZRR Picking Performance

Max. Picking Speed	2000 picks/hour (one robot arm)
Max. Object Weight	20kg
Max. Object Size Min. Object Size	W 500 mm, L 1000 mm W 50 mm, L 50 mm
Recovery rate	< 95%
Purity of End Fraction	< 98%

Learning system

Unlike traditional recycling machinery, that's based on mechanic and electric components, the Zenrobotics Recycler (ZRR) is powered by artificial intelligence (AI). The core of ZRR is ZenRobotics Brain, the unique software that analyzes the data and controls the robots. It's an essential part of the ZRR waste sorting system.

Just like a smartphone, ZRR gets software upgrades that make it even smarter and more efficient. Future software upgrades can add new features, such as additional fractions and new waste streams, or boost the effectiveness, precision, speed and capability of the current system.

ZRR is easily trained to introduce a new fraction for sorting, improve sorting quality of a fraction, or divide an existing fraction into new sub-fractions. Training works simply by showing ZRR samples of what to sort. During a training run, typical sample objects of desired fractions are placed on the sorting belt and run through the ZenRobotics Recycler. Training can be done quickly as the system learns on the spot.

High quality fractions

The sensor fusion integrated with trainable artificial intelligence (AI) solution opens possibility to train the ZRR system to recognize and pick new fractions as per customer needs. Currently, ZRR's pick various qualities of wood (a-wood, b-wood), mixed metal and inert fractions (gypsum, bricks, asphalt), rigid plastics and cardboard. ZRR can also be trainer to sort specific objects like tubes and pipes.

Furthermore, the picking precision and purity of fractions is key when output fractions are used as raw materials. Currently, the ZRR can reach up to 98% purity depending on the material and waste infeed.

Figure 4: Examples of some output fractions sorted by ZenRobotics Recycler

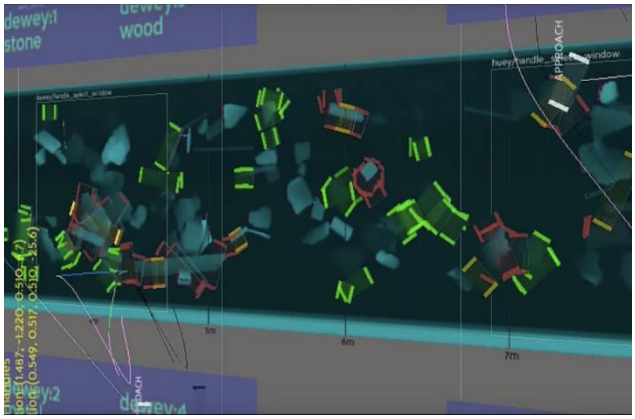
Mixed metals

A-wood

B-wood

Inert and stones

Mixed rigid plastics



Waste on the sorting belt as seen by ZRR

2. Implementation of the initiative

2.1 Planning of the initiative and actors involved

ZenRobotics Oy, founded in 2007, is specialised in development of robotics-based recycling technology. R&D has played a key role in the early stages of the company. The technology itself builds on the groundwork of ZenRobotics founders' (Harri Valpola, PhD and Tuomas J. Lukka, PhD) individual and group research efforts into machine learning and advanced algorithms during their years (combined 30+ years) in the academia in Finland (Universities of Jyväskylä and Helsinki, Aalto University) and abroad (Harvard, AI Lab Zürich). In total, ZenRobotics employees have published more than 100 peer-reviewed research papers. The company has been granted several patents, including the patents for the underlying technology of ZRR.

The ZRR system has been piloted since 2011 at SITA Finland, a part of SUEZ environment. In 2013 ZenRobotics and SUEZ environnement signed a Global Frame Agreement on the delivery of ZRR waste sorting systems. At that time SUEZ Finland involved typically in collection of the CDW wastes as mixed streams from renovation and construction sites in urban environment areas, where the limit space and typically strict timetables limited on-site sorting. SUEZ Finland saw an opportunity by introducing a new technology off-site to enable efficient and safe separation of valuable fractions from CDW.

2.2 Implementation of the iniatitive

In 2014 the world's first robotic sorting station was installed at the SUEZ Finland site (Figure 5). The line is the first installation that's designed and optimized around the robots. Currently the line is in daily production, processing mixed C&D waste. It has shown an increase in the utilization rate for the waste class from 70% to 90%. Important features in the development of the technology are discussed below.

Characteristics of CDW for robot waste sorting at Viikki sorting plant

Some key features of the waste streams received for treatment at Viikki are collated in Table 2. The actual composition of CDW from renovation, construction and demolition varies from case to case depending on the renovation, construction or demolition object. Currently, wood related materials play in volume a significant part of the received CDW. In Finland, asbestos and hazardous materials have to be removed prior to demolition or renovation (preauditting required in Finland).

Table 2: Characteristics of CDW for robot separation at Viikki

	Specification	**Remark**
Origin	Mainly mixed CDW from renovation, construction and demolition	Waste from renovations more challenging to sort than waste from construction. Waste from construction is generally of better quality (no material degradation)
Typical composition	Wood (voluminously main part), metal, plastic, concrete, bricks, stone, insulation materials, paper	
Impurities for sorting	Large (heavy) pieces, flat pieces (sheets, plastic foils, floorings), multimaterial CDW fractions (sandwish constructions), non CDW fractions, fine fractions (e.g. gypsum boards, plasters), bituminous waste (e.g. from roofing)	Especially large size impurities to be removed prior to robot separation
Waste acceptance procedure	Approval system including a visual check of each load	Non compliant materials are removed manually (by use of an excavator)

Increased Efficiency with Robotic Sorting

Traditional waste sorting plants are large facilities that consume a lot of energy. They require high initial investments and have very high operating costs. Furthermore, existing methods can separate only a limited number of fractions or specific particle sizes. Waste has to be processed by several items of equipment positioned one after another, leading to large plants and high energy consumption. There are also waste companies who operate very small facilities with inefficient excavators and labor-intensive manual sorting resulting in high operational cost.

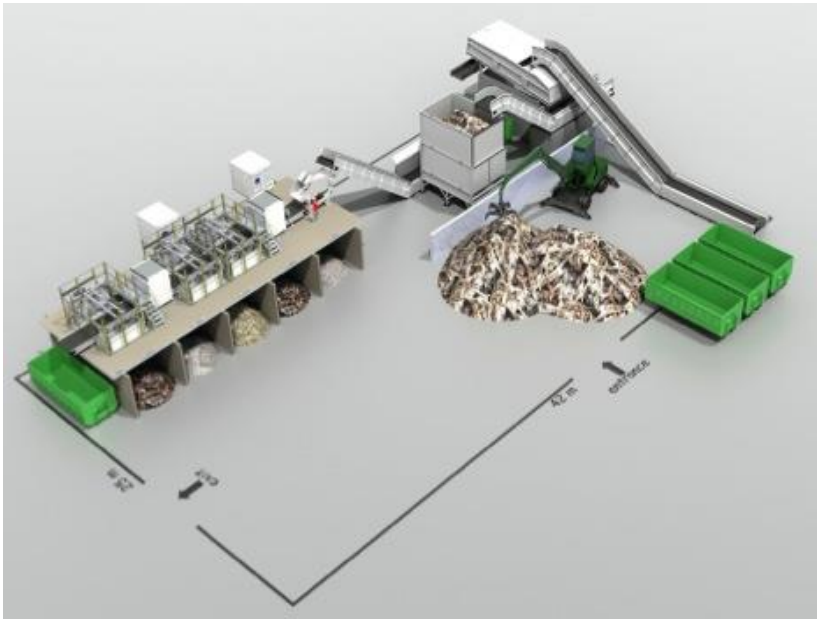
High initial investment required for setting up innovative facilities is a major barrier for waste management companies. Despite the increasing utilisation of automation in the facilities (drums, conveyor belts, etc.), manual labour is still required to guarantee the required purity of sorting materials. ZRR was designed to reduce the cost of recycling and increase the efficiency. Robotic waste sorting enables a lean, flexible solution. ZRR can be installed in a simple process with little additional equipment, allowing efficient waste sorting with few additional investments and low operating cost.

Investment and operating cost

The cost of ZenRobotics Recycler depends on the number of arms and optional features. The price range for a ZRR unit is typically between EUR 600 000 – EUR 800 000 in the EU.

The operating cost of ZenRobotics Recycler consists of electricity, maintenance and software license fee. The low energy consumption, 14 kW for ZRR2 with two arms, and minimum maintenance cost, ca. 2 euros per arm per operating hour, results in low hourly operating cost. Finally, the monthly software license fee for a ZRR2 model is 2350 euros. One of the main benefits of robots is possibility to work long operating hours as the hourly additional cost is not an issue compared to traditional energy-intensive machinery.

Figure 5: Robotic Sorting Station at SUEZ environnement, Finland. Pre-sorting with excavator, ballistic screen, bunker storage & vibratory feeder



Feeding and pre-processing

Robotic sorting requires some pre-processing, after which multiple fractions can be separated using only one ZRR system. First, an excavator sorts the largest objects from the waste batch. Next, the waste is screened in order to remove the light fraction (insulation materials, foils and paper) and fines (sand, very small objects). A vibratory feeder spreads the waste on the sorting belt as a so called singularized monolayer, meaning that most of the objects should not be overlapping. An even flow of material improves the recognision capabilities. Finally, the waste is run under a sensor module and picked by the robot arms. One robotic arm can sort up to 4 fractions at the same time, whereas two arms can pick even eight fractions at the same time.

Figure 6: Pictures 1 & 2 Typical input waste. Picture 3 Screened waste feed to ZRR

Separated streams and rejects

In the processing following streams are generated in the pre-processing:

- Impurities/large size pieces (10-20 % of waste stream) – large wood pieces to be mixed with wood the robot separated waste
- Flat pieces (around 20 %) – typically wood/plastics to be mixed with respective stream after robot separation
- Fines (30-40 %) – non usuable fraction for disposal or final treatment

Of the received CDW about 40-50 % are treated by robot separation. The recovery rate depends on the fraction and is high, if the system is optimised for the target material (e.g. metal, wood). The recovery rates of all fractions can be further improved if the reject after the robot separation is treated again.

The robot sorting system can be run based on two principles: sorting of several fractions with value or removing of impurities from a few selected high value fractions (e.g. metal). In future, metal separation on site might be interesting.

Examples of separated streams generated in robot sorting are collated in Table 3.

Table 3: Typically separated CDW from robot sorting (see also Figure 4)

Streams	**Specification**	**Remark**
Wood	Typically pieces of different sizes, separated as A and B wood	Large size wood pieces (e.g. wood beams) removed at pre-processing handled together with this stream For production of solid recovered fuel
Metals	Ferrous & non-ferrous metals	Furhter processed by metal recycling companies
Concrete & stone fraction	Inert waste	Waste further crushed and used in earth construction
Plastics	Pipes, window profiles, small pieces	Further treatment depends on quality, amounts. Material recycling for e.g. production of granulates possible.
Passing	Non separated fractions	The reject contains suitable for a second separation

Low Operating Cost

The overall performance is measured in recovery rate and produced tonnes. However, these numbers are heavily tied to both feeding of the material to the system as well as weight of the waste. In contrast to traditional methods, the ZenRobotics solution handles the waste with very little disintegration. When waste can be separated without shredding you get more clean fractions for reuse as pieces are not mixed together and most importantly it doesn't create additional fines fraction that is expensive to process. Also, heavier waste equals more produced tonnes. Robotic waste sorting thus reduces the need for energy-intensive and crushing of waste. This adds to the effieciency of the ZRR system. Finally, ZRR's low energy consumption (14 kWh for ZRR2) and minimum need for maintenance (2 euros per operating hour) ensures low operating cost.

The main benefit of automation comes from working in many shifts without stops and breaks. Therefore, a storage bunker can be installed before the robot system. This allows running the robot system when the rest of the sorting line is stopped, for example in the night.

Multitasking system for flexibility

The ZenRobotics Recycler is a multi-tasking system that adjusts to the ever changing needs in waste sorting. A single robot arm can pick up to four different fractions with high precision at the same time. The plant operator can easily choose the fractions they want to sort out. In the future more fractions will be available for operators as upgrades. With regular software upgrades operators can add new features, such as additional fractions and new waste streams, or boost the effectiveness, precision, speed and capability of the current system. This is the kind of flexibility that is not currently available in waste sorting.

A summary of advantages is presented in the box below.

Main advantages of robotic waste sorting

- **24/7 operation for cost efficiency.** Robotic systems are highly durable and require minimal downtime or maintenance. As additional working hours cost just little extra, you can sort materials that were not profitable to sort before.
- **Decentralization + simple process = higher profits.** ZRR can be set up in small, scalable units, reducing the need to transport waste to huge processing facilities. Also, there is no need to source separate waste streams, since ZRR can sort the waste to fractions as required.
- **Increased profits on recyclables and reduced waste costs.** High purity fractions yield better prices and easier sales of sorted materials.
- **Reduced labor cost.** Industrial robots work tirelessly around the clock. Once installed, the robots save lots of man hours every year and increase work safety by reducing personnel injuries during manual sorting.

2.3 Factors of success

The capabilities of the ZenRobotics Recycler system have been developed by in-house research of ZenRobotics, with both private and public funding, primarily by the private investors in ZenRobotics, but also Tekes (the Finnish Funding Agency for Technology and Innovation). The SME, with about 30 employees, has already raised €17 million in equity investments and its C&D ZRR has won several reputable cleantech awards.

Also, years of product development at the SUEZ Finland pilot site resulted in the Global Frame Agreement that was signed by SUEZ environnement and ZenRobotics in 2013.

Robotic waste sorting can be very rewarding especially when the entire process supports the requirements of the ZenRobotics Recycler. Proper pre-processing and feeding can result in increased quality of output fraction. This has been seen at SUEZ Finland, where the entire plant is designed around the robots. There has been an increase in the utilization rate for the waste class from 70% to 90%.

3. Lessons learned

The market potential for ZenRobotics Recycler is clear as the system will provide waste management companies unprecedented purity of sorted material at a lower operating cost, compared to existing methods. The < 98% purity of sorted materials will provide additional income to waste management companies through selling the materials as resources, whereas significant savings are derived from reducing the amount of landfilled residue. Accordingly, the ZRR provides operators with major advantages over competing solutions, including both economic, as well as environmental.

Main benefits as perceived by customers:

- Customer 1: “We have been able to increase the utilization rate for the waste class from 70 % to 90 %. After all, it’s about increasing efficiency.”
- Customer 2: “We were looking for alternative ways to reduce our dependency on manual sorting for the years to come as finding people who are willing as well as skilled was becoming harder every year. Also, the ZRR brings endurance a human can’t deliver: permanent concentration and speed.” “We believe that robotic sorting will lower our costs, while continuity will increase.”

3.1 Preconditions for application of the initiative - replicability

The ZenRobotics Recycler (Figure 8) can be installed in most C&D waste-processing sites. The type of installation depends on the existing process. The ZRR system can be installed as a retrofit to an existing sorting line, for example to replace manual sorting, or as a stand-alone system. The planning always begins from analyzing customer needs and sorting task, what kind of waste do they process and how much.

The trainable AI technology opens the possibility to modify the system per operator needs and requirements in the business environment. For example, certain fractions such as red brick are valuable in some markets. The customer can choose whether or not to sort out that specific fraction. This kind of flexibility and option for localisation is not currently widely available in waste sorting.

3.2 Innovation potential

The ZenRobotics Recycler is the first robotic waste sorting system in the world. Its novel approach and unique value proposition are perfectly inline with the rapidly growing market for smarter waste management technologies.

The technology enables new kinds of possibilities for the waste industry. First, with increased automation companies can easily increase the efficiency of waste sorting, resulting in lower cost per produced ton of end fractions. Secondly, with new and improved recognition capabilities recycling companies have the opportunity to sort new kinds of waste types of high quality. This material can be used as raw material in producing new products. Finally, with a multitasking technology waste companies can sort out more materials with fewer machines. This enables smaller and leaner waste processing lines with low energy consumption and low operation cost.

In a nutshell, increased waste sorting efficiency will increase the willingness to sort waste more thoroughly as the cost of the processing declines. Also, the possibilities to recognize and sort out totally new types of fractions, such as red bricks, create new business opportunities for waste companies.

In future, semimobile system installed e.g. on-site, would offer new possibilities.

Figure 7: Overall photo of a ZRR

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