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Collection and Separation of Municipal Waste by Semi-underground Containers – a Case Study

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Abstract: The paper deals with the issue of collection and separation of municipal solid waste. The latest trends in the subject area are presented. Attention is focused on the possibility of applying semi-underground containers in densely populated urban areas. The authors of the paper prepared a study of the feasibility of using such containers in the city district of KVP Košice. The paper also includes computer simulations of container stand design.

Keywords: waste collection, separation, container

1. Introduction

Even during the initial design of the product, it is necessary to anticipate what will happen at the end of its life and where her it can be disposed of. An effective solution is waste separation and subsequent use of materials, the so-called recycling. Over the last 20 years, there has been a growing interest in waste separation on a large scale, which is also subject to new development trends. New technologies and methods of waste collection for its subsequent disposal are emerging [1].

As the amount of waste increases, so do the demands on hygiene and the requirements for the waste management system, which traditional systems cannot meet or the operating costs increase. One possible solution is the efficient use of underground space. Examples are functioning sewer systems, water, gas and the like. Underground systems can operate as automated vacuum collection, where waste is transported using pneumatic systems, or as separate collection points. Both systems can collect all types of waste [2].

New possibilities for waste management systems and strategies in the future include the use of underground freight transport and research and development of multi-purpose tunnels, which will bring benefits in terms of cost-effective and better environment. In 2050, 50.6% of the population is expected to live in cities, creating a mismatch between sustainable development and deteriorating living conditions in cities [2] [3]. Untapped underground space has the potential to improve these problems, providing new space for development.

A step towards better waste management is the semi-underground container collection system, which is gradually expanding for all types of waste management [3]. The system has been evolving from the 1980s to its current form. A characteristic feature is that its 2/3 part is hidden in the ground. This ensures that the waste is kept cool and the spread of odors is reduced.

2. Waste production analysis

In the EU countries, the production of waste from households and the economy reaches 2 502 million tons, of which about 2 336 million tons are processed. Each person living in the EU disposes of an average of half a tonne of municipal waste a

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year. Waste produced in production reaches 360 million tons and in construction 900 million tons per year. Water supply and energy production will produce another 95 million tons per year. In total, the European Union produces up to 3 billion tons of waste per year [4]. According to The Guardian, up to half of the food produced (2 billion tons) ends up as waste [5].

In highly developed countries in urban areas, one person produces on average up to 1.4 kg of waste per day. In contrast, in less developed countries, urban dwellers produce around 0,6 kg of waste per person per day [2]. As the population increases, urban waste is expected to grow by up to 45 % in developing countries. The urban population will have to deal with this and focus on urban waste management [6].

2.1. Analysis of separated collection in Slovakia

In the volume of municipal waste production, Slovakia is below the average per capita within the European Union (Figure 1). In 2020, 2 434 039 tons of municipal waste were produced in Slovakia. Nevertheless, the unfavorable situation in the management of such waste persists in Slovakia. On average, one inhabitant produces 446 kg of municipal waste, which represents an increase of 12 kg compared to 2019.

In the long run, a high share of landfilling remains, at 48.4 %. The goal arising from international regulations is to reach a level of municipal waste recycling of 55 % by 2025 (currently 43.7 %) and to reduce its landfill rate to less than 25% by 2030. Observing the development of a sorted collection of municipal waste, a slightly increasing trend of the amount of sorted components of municipal waste can be seen, however, in terms of the obligations of the Slovak Republic in the area of preparation for reuse and recycling of waste, sorted collection needs to be significantly intensified [7].

The recalculations show that biodegradable municipal waste is the most represented component in mixed municipal waste. It is interesting that non-sorted waste makes up 13.2 % in the case of complex housing construction and 1.8 % in the case of individual housing construction. This points to great possibilities for reducing the amount of mixed municipal waste.

Within the municipal waste management systems, which must currently be introduced in the municipalities of the Slovak Republic, the amount of

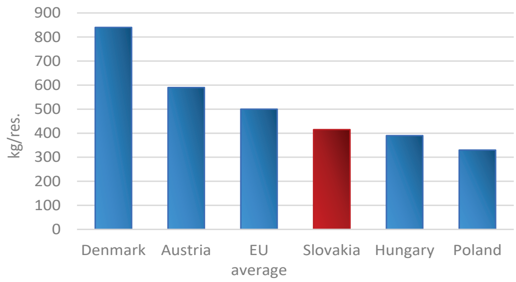


Figure 1: International comparison of municipal waste generation [7]

mixed municipal waste could be reduced by about 80%. The aim is to reduce the amount of mixed municipal waste by 50% by 2025 compared to 2016, when 1 184 729 tons of mixed municipal waste was generated [8].

2.2. Separate waste collection in Košice

The city of Košice ensures the collection, disposal and removal of municipal waste through 100 l bags, 110-120 l kuka-containers and 1100 l containers according to the schedule that is determined (Figure 2). Municipal waste management is provided by a contractual partner, KOSIT a.s. Košice [9].

The largest category of waste they deal with is a thermally disposed waste (Figure 3). It makes up 66 % of the total waste. Overall, the amount of plastics and oils decreases, but the proportion of separated paper increases. The amount of separated raw materials depends on the level of management of the Slovak Republic and its regions, respectively involvement of producers. An important part of the separation is the price of purchase commodities [9] [10].

3. Underground waste collection systems

Underground waste collection systems can be divided into two types:

1. *automated vacuum collection in which the waste is pneumatically transported to a central facility,*
2. *a separate collection point.*

With both systems, it is possible to collect all types of waste.

3.1. Pneumatic waste collection system

One of the modern trends is the pneumatic waste collection system, which acts as a vacuum cleaner and is based on the principle of storing waste in input containers for each type of waste. The waste is then transported by pipeline to the containers at the waste station (Figure 4). Such

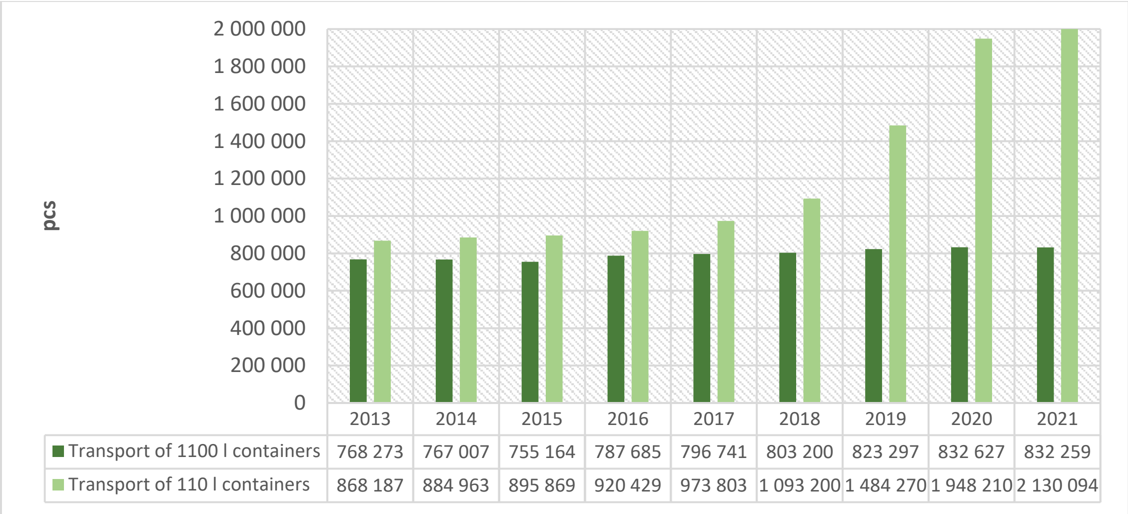


Figure 2: Waste collection and disposal in Košice [9]

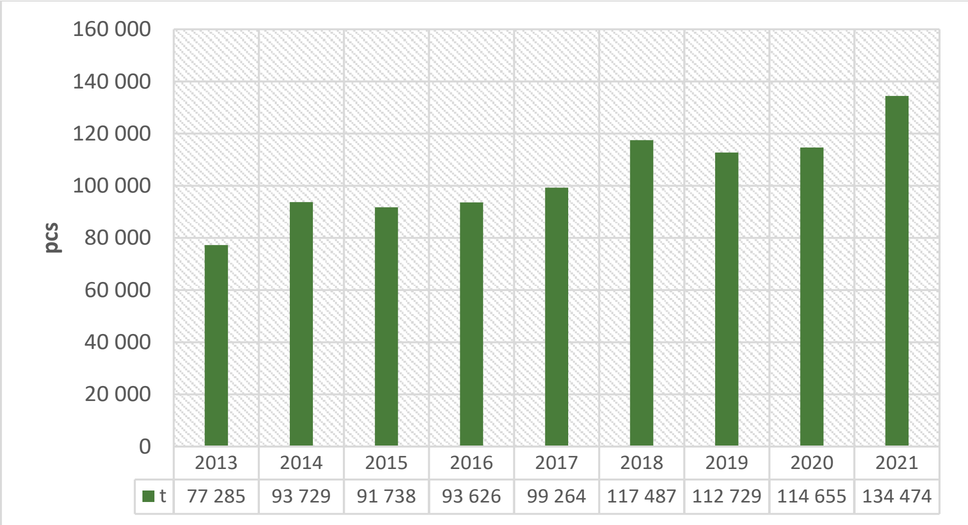


Figure 3: Imports of waste for energy recovery [9]

a system reduces staff costs as it is monitored remotely. Waste vehicles and fuels are also being saved. Typical areas of application for the pneumatic waste collection system are large metropolitan and residential areas, high-rise buildings, public spaces, medical facilities, hotel and office complexes [11]. This system is designed to have a service life of at least 60 years, mainly for pipeline and waste supply [12].

The main steel transport pipe has a diameter of 500 mm and is hermetically welded and sealed. The number of waste bins depends on the number of waste fractions, the volume of waste and the frequency of emptying. For bio-waste, a tank is used instead of a container. Once the tank is full, it is replaced by a new tank in order to maintain a high level of hygiene throughout the system [13] [14]. The Abu Dhabi Automated Waste Collection Case Study describes the operating principle of a pneumatic waste management system, which states that when waste is placed in a vertical tube known as a waste chute, it falls into a temporary collection chamber due to gravity. Vacuum extractors create a vacuum in the pipes, which sucks up waste bags when the valve is opened. The waste travels at a speed of up to 80 km/h to a collection point, where it separates from the air in a cyclone separator. It is then placed in a press, which compresses the waste into containers. The modular network consists of 16 km of pipelines and 184 drain valves. The frequency of emptying cycles varies according to local waste production [14], [15].

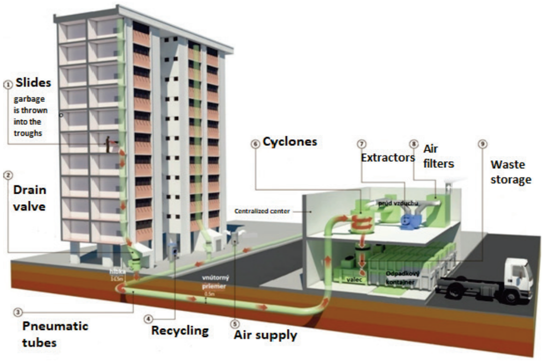


Figure 4: Pneumatic waste collection system [14]

3.2. Waste collection system using underground containers

The system of collecting municipal waste using underground containers has been evolving since the 1980s, to its present form (Figure 5). The most well-known company dealing with this collection system is the Finnish company Molok. The Molok container is installed partially underground and uses the laws of gravity and the cold of the earth. The aim is to achieve maximum waste management capacity in a minimum of space. Molok is more attractive than conventional containers, resistant to wildlife and is odorless. As it has a larger capacity, its emptying is less frequent, which saves resources [16].

A reusable lifting bag is installed inside the container, which is 2/3 installed in the ground (Figure 6). The lid of the container is removed during emptying and the bag is pulled out of the

Figure 5: Examples of Molok underground containers [16]

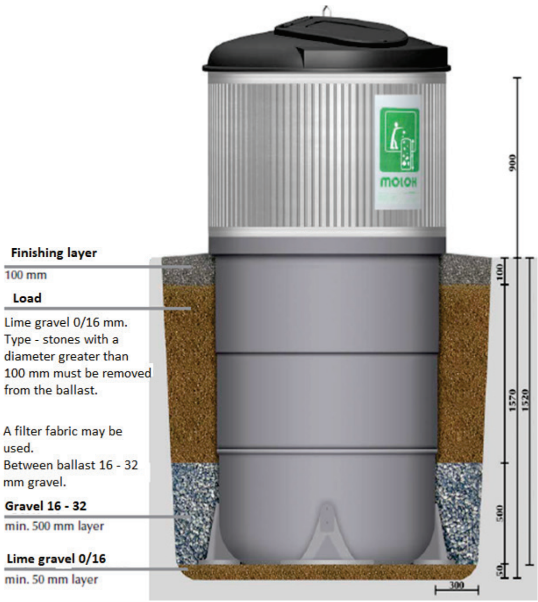


Figure 6: Molok Klasik container and its installation [18]

well by a patented mechanism. The lower part of the bag is released and thus the waste is released. The bag is then placed back in the well. The whole process takes about 3 minutes [17]. With a vertical construction and due to compaction, the capacity is about 5 times greater per unit area compared to a surface container.

The collection containers are installed to a depth of 1.5m and before the actual installation, the location of electrical cables, water pipes, sewers and, last but not least, the type of soil must be taken into account. There must be sufficient space around the container for safe emptying. The distance between the individual containers should be at least 300 mm, due to the access of the unloading vehicle during winter operation [18].

In order to withstand solvents, rust and noise during emptying were as low as possible, polyethylene plastics were used to make the container. Polyethylene has a high strength-to-density ratio, thanks to which the container has thinner walls, is resistant to corrosion and many solvents. They also have a great advantage when

Figure 7: Container filling level monitoring solution

collecting bio-waste, as there is a special separation plate at the bottom of the container, so it separates liquids and solid waste at the same time [19].

The solution that optimizes collection vehicle routes and automates the waste collection plan is a remote wireless ultrasonic sensor (Figure 7). This sensor provides mapping of the filling status of containers, thus optimizing collection plans. Emptying baskets that are less than 25 % full is a waste of fuel, time, resources and money. The driver receives information about the routes and determines the emptying plan himself. Ultrasound sonar and software not only measure waste levels, but also capture events such as fire or vandalism [20] [21].

4. Case study of logistics and collection of separated waste

As part of a pilot project for the modernization of container stands, the first underground containers were installed in Košice in 2017. In the Košice-South district, fifteen 1 100 l waste containers were replaced by three 5 m^3 underground containers. Following this, semi-underground container sites were built in the West district (Figure 8). They consisted of three 5 m^3 containers for municipal waste and three 3 m^3 containers intended for separate collection of paper, glass and plastics. The biggest advantage of these projects was the aesthetics. The search for a suitable location proved to be problematic, as the city of Košice is overcrowded with engineering networks.

For our design, a location was selected at the KVP housing estate in Košice, which is 6 km away from the city center. At present, there are approximately 23 864 inhabitants and it is one of the largest parts of Košice.

In this part of the city, waste is collected 3 times a week - Tuesday, Thursday and Saturday. Based on the population, the company creates a schedule according to which they collect paper, glass and plastics.

The aim of the separate collection logistics study for the proposed city district of KVP is to reduce costs. As so far waste collection has taken place 3-times per week, the proposed project would reduce this number to 1-time per week. In some parts, the collection would take place only once every two weeks, which would significantly reduce not only transport costs but also environmental costs for the proposal. Emissions are expected to be reduced by 30 % to 70 % compared to the current system.

The design of the container is an important part of the design. The waste collection point should be a harmonious part of the overall appearance of the environment. The larger the volume of the container, the lower the number of current stands and containers. Its depth prevents the formation of black dumps and entry by unauthorized persons. The likelihood of access of animals and the spread of undesirable odors is also reduced as cold reduces the formation of bacteria. The projects were designed for the selected street and their installation depends on the population density and the amount of waste produced. (Figure 9 to Figure 14).

The project design was focused on the most common combination of containers. The reason for the proposal is to reduce the number of stands and reduce costs. The delivery distance, the number of inhabitants living in the area and the accessibility of the site for collection vehicles must not be forgotten in the design. Different materials and colors are used in the design, with an emphasis on aesthetics in the given locality.

Figure 8: Semi-underground containers in Košice – West

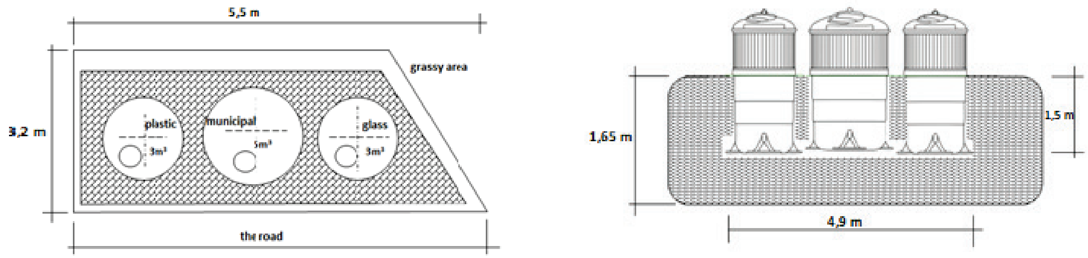


Figure 9: Project proposal No.1

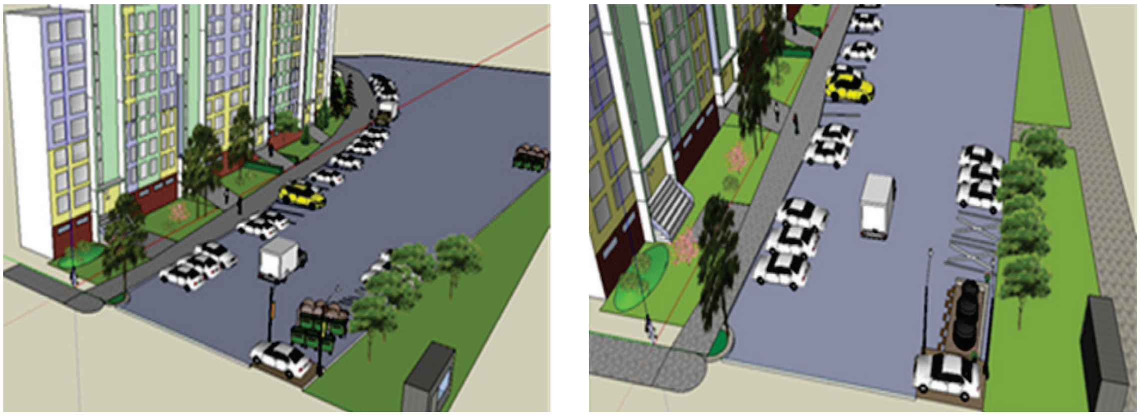


Figure 10: Assessment of the original site and implementation of project No. 1

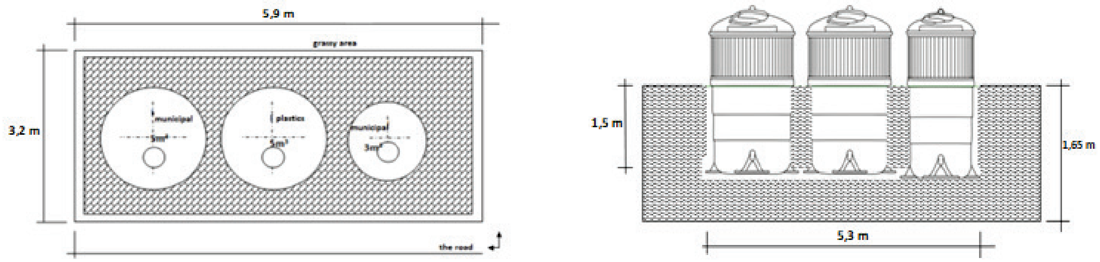


Figure 11: Project proposal No. 2

Figure 12: Assessment of the original site and implementation of project No. 2

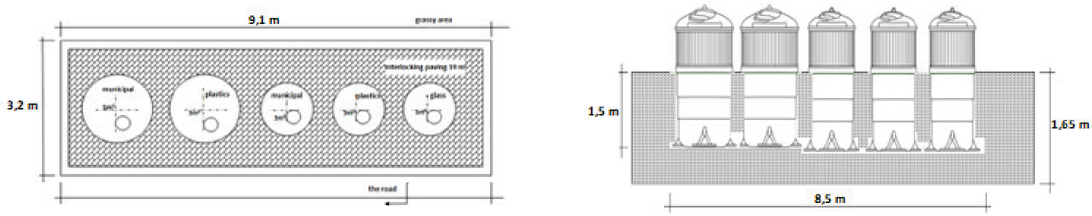


Figure 13: Project proposal No. 3

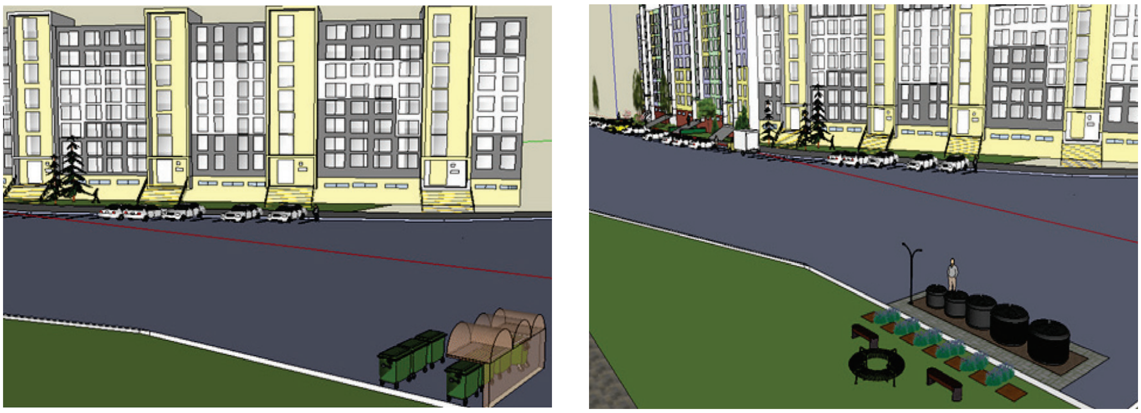


Figure 14: Assessment of the original site and implementation of project No. 3

4.1. Economic evaluation of the proposed project

The aim of the study was to reduce the current costs of separate collections. It is therefore necessary to take into account investment costs, maintenance costs, operating costs and, last but not least, environmental costs. The first step to logistics design and design evaluation is the correct location of collection points and their evaluation.

Approximately 730 containers with a volume of 1 100 l are placed in the proposed area, of which municipal waste containers represent 63 %, plastic 16 %, glass 14 %, paper 5 % and tetrapack containers 2 %.

The implementation of a semi-underground container stand requires a thorough mapping of the area and processing of technical documentation in order to prevent interference with the engineering networks. The initial costs of implementation are associated with excavation work, construction of stands and the purchase of cars. Container construction requires the calculation of the excavation pit volume, as it is necessary to know how many layers of material will be required for backfilling.

Table 1: Calculation of percentage for backfilling of the excavation pit 3 m^3

X1	50 mm	3.19 %	0.12 m^3
X2	500 mm	31.85 %	1.17 m^3
X3	920 mm	58.60 %	2.16 m^3
X4	100 mm	6.36 %	0.23 m^3

Table 2: Calculation of percentage for backfilling of the excavation pit 5 m^3

X1	50 mm	3.19 %	0.16 m^3
X2	500 mm	31.85 %	1.56 m^3
X3	920 mm	58.60 %	2.87 m^3
X4	100 mm	6.36 %	0.31 m^3

Table 1 and Figure 15 show the calculation of layers for backfilling the pit of a container with a volume of 5 m^3. The backfill of the Molok 3 m^3 excavation pit is shown in Table 2.

The procedure for excavating the stand consists of a pit 1.57 m deep, where the width depends on the number and volume of installed containers. In the lower part there is a calcium gravel with a diameter of 0/16 mm and a minimum height of 0.05 m. The gravel is then smoothed with a vibrating plate and a container is placed on it. The second part consists of gravel with a diameter of 16 ÷ 32 mm to a height of 0.5 m. Subsequently, a geotextile and a load consisting of excavated soil up to a height of 0.92 m are placed on it. The finishing layer should be at least 0.1 m high consisting of aggregate or interlocking paving (Table 3).

Table 3: Molok excavation price 5 m³

Excavation price of 5 m³	Molok container	price of 1 hole
Excavation work	22 €/hour	22 €
Vibrating plate	15 €/3.5 hours	15 €
Crushed gravel 0.16	6.72 €/tons	1.10 €
Gravel 16÷32	7.34 €/tons	11.45 €
Geotextile	0.48 €/m²	1.75 €
Gravel 32÷63	9.60 €/tons	2.976
Container price		3 100 €
		3,154 €

The price of the container itself ranges from 2 650 € to 3 200 €. It depends on the volume, internal structure and external appearance of the container. In this study, the most common placement of current containers and their composition were taken into account (Table 4).

The use of waste monitoring systems also contributes to reduction of the costs from 10 % to 20 %.

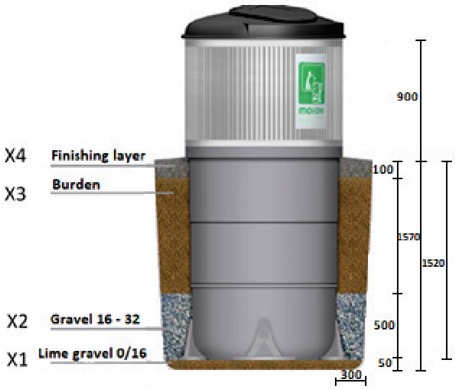


Figure 15: Backfill of the Molok excavation pit

An important part of the project is a collection vehicle, the price of which varies depending on the type from 170 000 € (Figure 16). It is possible to use a car with a hydraulic arm, which uses a collection platform for waste collection. Another option is to combine hydraulics and a classic collection vehicle. The most expensive is a vehicle that compresses waste, but it is recommended to install at least 200 stands.

Finland, which was the first pioneer of such containers, evaluated (according to the previous experiences) that the semi-underground containers reduced the costs of waste collection (Figure 17).

Table 4: Quantification of the proposed projects

Project 1	**Price**	**Project 2**	**Price**	**Project 3**	**Price**
Excavation work	44 €	Excavation work	44 €	Excavation work	44 €
Vibrating plate	30 €	Vibrating plate	30 €	Vibrating plate	30 €
Crushed gravel 0.16	3.40 €	Crushed gravel 0.16	3.50 €	Crushed gravel 0.16	5.70 €
Gravel 16÷32	36.00 €	Gravel 16÷32	37.45 €	Gravel 16÷32	60.35 €
Geotextile	5.25 €	Geotextile	5.25 €	Geotextile	8.75 €
Gravel 32÷63	8.25 €	Gravel 32÷63	7.50 €	Gravel 32÷63	13.50 €
Container price	8 950.00 €	Container price	8 600.00 €	Container price	14 800.00 €
	9,077 €		**8,728 €**		**14,962 €**

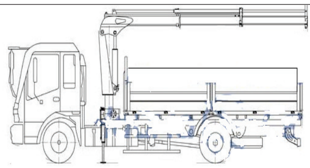
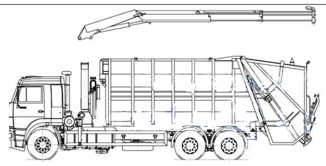
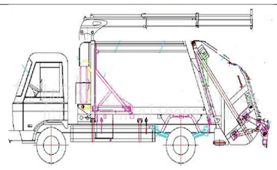
Harvest with hydraulic arm	**Combined collection**	**Rear-loading vehicles with mobile compactor**
		

Figure 16: Types of collection cars

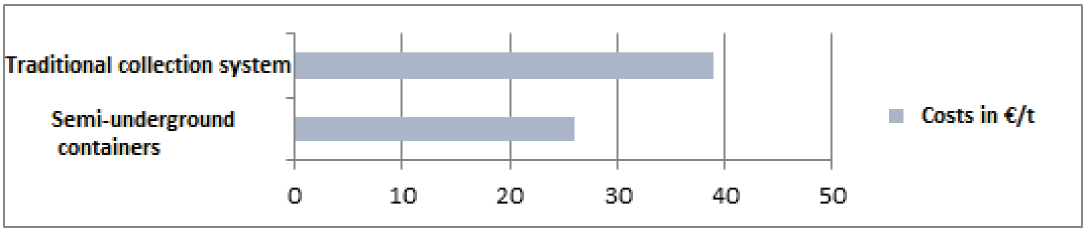


Figure 17: Comparison of operating and investment costs for the collection of mixed municipal waste

Table 5: Comparison of the costs of traditional waste collection with the costs of semi-underground containers

		KVP Košice			
		Traditional containers 1100 l		**Semi-underground containers (5m³, 3m³)**	
		pc/count	€	pc/count	€
Investment costs	The price of containers	731	253 682 €	282	823 800 €
	Construction price	125	37 500 €	94	21 852 €
	Collector cars	8	1 360 000 €	3	960 000 €
			1 651 182 €		**1 805 652 €**
Operational costs	Work	24	18 000 €	4	3 124 €
	Maintenance		20 150 €		730 €
	Fuels		14 720 €		6 980 €
Environmental costs	Occurrence of emissions from fossil fuels burning		**52 870 €**		**10 834 €**

The comparison of the costs of traditional waste collection with the costs of semi-underground containers is divided into certain lines (Table 5). The first such landmark is investment costs. For these costs, we take into account the prices of containers, the price of construction of stands, the price and number of collection trucks.

Semi-underground containers are more expensive because they are supposed to replace the existing system, but they have a larger capacity, they replace 6 existing containers, they are made of high-quality materials, and their service life is much longer. Despite of the fact that the investment costs in semi-underground containers are greater, the return on investment is faster than with traditional containers.

5. Conclusions

The aim of the feasibility study of the application of semi-underground containers in the most populated district of KVP in Košice was to demonstrate the validity and economic advantage of such a solution. It has been shown that the proposed solution can reduce the total cost of collection of MSW from 20 % to 30 % compared to the use of traditional containers. Another important fact is the reduction in the number of collection vehicles required and the associated maintenance and fuel consumption. Despite the higher investment costs, the return on the proposed method of MSW separation is faster than when using traditional containers.

It is assumed that the feasibility study will be a motivation for the company Kosit a.s., Košice.

Acknowledgments

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