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EXEMPLIFYING THE ZERO-WASTE CONCEPT IN SMART CITIES

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ABSTRACT: Due to the environmental imbalance on our planet, the concept of zero waste is gaining importance day by day. It is essential in the aspect of production and consumption cycle management and responsible waste management in urban space. The aim of this article is to exemplify methods of reducing waste in smart cities according to the author's Waste Management for Generation, Environment, and Gains (WM2GEG) scheme. A structured interview method was used to collect data, and the research sample was selected using the Smart City Index 2020. The study identified environmentally, socially friendly, and economically beneficial methods of rational waste management, such as composting organic waste, creating underground waste containers, and incinerating waste with energy recovery. Specific ways to reduce waste are also presented, such as banning disposable packaging and obtaining energy from renewable sources.

KEYWORDS: zero waste, waste management, smart cities

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Introduction

The amount of rubbish generated by people increased massively with the rapid increase in consumption in the 2nd half of the 20th century. Companies all over the world, in order to increase their sales, started to produce more and more consumer-friendly, lightweight products, often disposable ones. Too much packaging serving an aesthetic function only began to be used. The societies of all countries quickly became accustomed to this convenience, and the consumption of perishable products and their packaging increased significantly (Szaky, 2013, p. 8). As R. Murray points out (2002, p. 1), waste is the dark side of the economy. Rubbish is not only generated by the final consumer by throwing away unnecessary packaging or used products. They are also created at all stages of production, regardless of the industry of operation.

For some time, rubbish was treated only as a threat to human health, to be removed quickly and effectively from urban space. Most often, waste was sent to a variety of landfills. As environmental awareness grew, people began to think more and more about the sustainable use of limited natural resources (Nizar, 2018, p. 2). Terms such as zero waste, sustainability, or smart cities increasingly appeared in the scientific literature, referring, among other things, to the need to take care of a kind of symbiosis between economic and social development and the natural environment.

The paper aimed to exemplify waste reduction methods in smart cities in line with the author's WM2GEG scheme. The presented study is an extension of previous scientific research related to the fight against ever-growing rubbish heaps. It may also be of great cognitive value to municipal authorities and organisations supporting the waste management process in urban centres. Learning about the practices and methods used by other cities around the world may inspire the creation of new organisational and technological solutions for rational waste management. The information collected in this paper may also be relevant to city dwellers, especially those with pro-ecological interests.

An overview of the literature

The smart city concept emerged in literary theory in the late 20th century. R. Hall et al. (2000), among others, wrote about smart cities, claiming that the smart city is the urban space of the future, which is, above all, environmentally safe and efficient. All systems and processes within it are coordinated electronically. The key for smart cities is the enrichment of urban

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systems with an array of sensors connected via computer networks and configured with databases. An infrastructure coordinated in this way greatly facilitates the management and decision-making processes (Hall et al., 2000, p. 1). Among others, Singapore was cited as an example of a smart city of the time (Mahizhnan, 1999).

Over the years, researchers have put forward different explications of smart cities. According to Forrester Research, a smart city is a place where information and ICT are used to improve the efficiency of public safety, administration, communication, and education (Bélissent 2010, p. 3). The anthropocentric aspect is also highlighted, i.e. the maximum comfort of life for residents (Shapiro, 2006) with the minimum use of resources simultaneously. In turn, M. Zuccalà and E. Verga (2016, p. 826) consider the smart city as a sustainable urban centre, characterised by the support of ICT in all areas of life and by the integrated management of building resources, energy systems, mobility, and ecological systems.

Administration, transport, construction, heating and cooling systems, health care, education, waste management, and spaces for leisure and recreation are usually cited as the main infrastructure elements in smart cities (Bélissent, 2010, p. 8). The key to defining a city as smart is to achieve a high level of efficiency in all these elements of the urban infrastructure and thus increase the well-being of the inhabitants. In addition to creating appropriate urban infrastructure, preferably one that is fully self-sufficient (e.g. by using energy generated from renewable sources), smart cities are characterised by intelligent management. Authorities should pay attention to all infrastructure sectors at every stage of city management. When planning the budget and making executive decisions, the representatives of the administration must not overlook any of the sectors that are important for the life of the city (Jelonek, et al., 2020). A very important element in this aspect is the circulation of information and the possibility to quickly finalise official matters, e.g. thanks to digitalisation (Bokolo, 2021), the creation of special electronic platforms, and the use of robotic process automation (RPA) (Sobczak & Ziora, 2021).

B. Cohen (2015) distinguishes three generations of smart cities. The smart city 1.0 generation is an initial stage of development characterised by the technological modernisation of urban space. The most important thing here is the implementation of modern information technologies that enable the proper shaping of the city. Technology companies are mainly active at this stage. Smart city 2.0 generation – a phase of city development in which the authorities play the leading role. At this stage, they are initiators of the implementation of new technologies, the use of which should positively affect the improvement of citizens' lives (Vishnivetskaya & Alexandrova, 2019).

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The next stage is smart city 3.0. An important aspect here is the strong involvement of residents in the development of their city. This involvement is manifested, inter alia, through the participation of citizens in making decisions by representatives of public administration and acting in accordance with the policy adopted by the authorities (Bednarska-Olejniczak, Olejniczak, 2016, p. 760). Internet platforms enabling citizens to participate in the creation of a smart city 3.0, such as Taipei Smart City Project Management Office (Smart Taipei), are becoming more and more common.

To create intelligent urban infrastructure systems, it is necessary to ensure the integration of infrastructure systems (Stepniak, et al., 2021) and access to sustainable energy resources (Zuccalà & Verga, 2016, pp. 827-830). Energy is indispensable for all economic activities and, thus, for developing individual territorial units (Hajduk & Jelonek, 2021, p. 2).

The activities aimed at the implementation of the idea of sustainable urban development (Khan et al., 2020), implementation of the green economy concept (Addanki & Venkataraman, 2017), circular economy concept (Sobol, 2019), waste management (Esmaeilian et al., 2018), or reducing the carbon footprint (Turek et al., 2021) are of particular importance in the smart cities development. Seeing the problem of huge amounts of rubbish created every year in urban spaces, scientists have created a new concept that can be a recipe for the growing mountains of rubbish – Zero Waste. As emphasised by Ch. Cole et al. (2014, p. 65), there are many different definitions of Zero Waste (ZW), depending on the primary purpose of the activities in question. Some of these explications refer to reducing landfill waste, while others to avoiding waste in marine waters. For the purpose of this article, it is assumed that ZW is the management of products and processes that allows for the systematic avoidance of waste or its treatment to recover all resources (Zaman & Lehmann, 2011, p. 177). ZW implies the continuous elimination of waste at each stage of a product – from production, through distribution, to consumption and disposal of product residues (packaging, leftovers). Actions in line with ZW support the transition of countries or regions to a closed-loop economy (Kerdlap et al., 2019).

One of the concepts of rational waste management is the Zero Waste Hierarchy of Highest and Best Use. The model consists of seven levels. The first level, Rethink/Redesign, refers to the thoughtful design and purchase of products. The next level is Reduce, which encourages producers and consumers to carefully plan the consumption of the goods and services they purchase. This applies especially to perishable products such as perishable food. Producers and consumers should reduce waste, especially non–recyclable or non-reusable waste. The need for such restrictions has been recognised by scientists and some politicians for several decades – an example of a country that has successfully reduced the amount of non-reusable or recyclable rub-

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bish in England. Between 2000 and 2010, it decreased the amount of such waste produced by households by as much as 29%, from 22.2 million tonnes to 15.8 million tonnes (Phillips et al., 2011, p. 336).

The third level is Reuse, which, according to ZWIA (2018), involves maximising the reuse of materials and products by keeping them in good condition, repairing, refurbishing, or – alternatively – putting them to alternative uses. The necessity of the reuse principle is pointed out, among others, by Kerdlap et al. (2019, p. 3). In smart cities, it should be used both by businesses (e.g. restaurateurs ordering fruit and vegetables in reusable boxes) and by individuals (e.g. by donating unnecessary equipment, clothes and textbooks to other users).

The fourth level – Recycling/compost, refers to the creation of systems, enabling materials to be conserved and kept in their original product loop (ZWIA, 2018). This refers to recycling materials, i.e. processing them to make new products (Cole et al., 2014, p. 66). Recycled materials can be glass, plastic, paper, or metal. In doing so, it is essential that the plastics being recycled have the right chemical composition and do not contain components harmful to the environment. The starting point for effective recycling is the proper selection of waste. Organic waste, in turn, should be composted, which after a suitable period of time can be used as a high-quality natural fertiliser for gardening.

On the other hand, material recovery involves trying to extract valuable materials from mixed waste by screening them in specialised sorting facilities. Where conditions allow, it is also acceptable to recover energy from residual waste sorting but only using systems that operate at biological temperature and pressure.

The next level is Residuals management. This means, first and foremost, examining the residual waste in order to improve the management system and minimise the impact of fermented materials by stabilising them biologically. It is essential to answer the following questions: What waste remains and why? Which materials should be removed from circulation? How should residual waste be managed after all the previous steps have been taken in accordance with the ZW Hierarchy?

The last level – Unacceptable – can be interpreted as unacceptable actions. It refers to the non-acceptance of policies and systems that contradict the previous levels. Destruction of recyclable materials and energy disposal systems that depend on continuous waste production should not be encouraged. It is also important not to allow toxic substances into consumer goods.

W. Zulfikar et al. (2021, p. 17) point to 5 main principles of the ZW concept, defined as the 5Rs. These principles are refuse, reduce, reuse, recycle, and rot. The refuse principle calls for consciously making choices about the

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goods and services purchased and forgoing those harmful to the environment. The reduce principle reduces unnecessary use of resources and products, e.g. through thoughtful purchasing. While both principles refer to reducing waste by not purchasing a particular product or service, the last three (reuse, recycle, and rot) refer to products or services that the consumer/producer has purchased.

Various approaches to the R-principles of ZW can be found in the literature. For example, F. Compagno (2020) shows reduce, reuse, and recycle as the most essential principles of ZW, while B. Johnson (2013), and R. Müller and S. Schönbauer (2020) mention refuse, reduce, reuse, and recycle.

However, irrespective of the number and type of R-principles mentioned by individual researchers, the main aim of ZW activities is to reduce the impact of man-made waste on the environment as much as possible (Phillips et al., 2011, p. 336). All principles stem from a common-sense approach to the issue of rational consumption of goods and services. It is worth introducing them in all regions of the world, but above all, they should be the hallmark of cities defined as smart cities.

As research shows, rational waste management is important for at least several reasons. First of all, reducing waste is good for society. Less rubbish means reduced concentrations of pathogens (Ross, 2011, p. 778). At the same time, reducing waste minimises the production of greenhouse gases, saves energy, and conserves renewable environmental resources (Heimlich et. al., 2007; Chen et al., 2011).

Research methods

The main rationale for this study was to try to answer the question: why apply the zero waste concept in the urban waste management process? This question was considered primarily in relation to further questions and objectives related to the research process. However, it inspired the creation of the author's scheme for the purpose of applying the zero waste concept, which was referred to as WM2GEG (the name is an acronym for Waste Management for Generation, Environment, and Gains). It is presented in Figure 1.

According to WM2GEG, rational waste management has three main types of beneficiaries. The beneficiaries of rational waste management are the people ('for a generation'), both those who have started these activities and future generations. In view of the rapidly growing population on Earth and increasing consumption, it is crucial to stop the changes resulting from the increasing amounts of rubbish produced by society.

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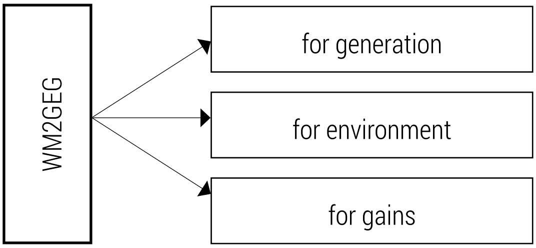

Figure 1. WM2GEG waste management target scheme
Source: authors' work.

Another beneficiary is the environment ('for environment'), which survives provided that factors harmful to the ecosystem are reduced, e.g. greenhouse gases, toxic substances used in the production of chemicals, etc., and non-renewable natural resources are conserved. Some of the waste management activities may produce visible results within a few years or so.

A third aspect included in the WM2GEG scheme is economic consideration, referred to as ('for gains'). Skilful waste management in a given territorial unit may increase savings of consumers and producers, e.g. by buying energy-efficient equipment and replacing more expensive in the long run disposable packaging by ecological reusable packaging, and of entire territorial units, e.g. savings resulting from recycling part of the waste or recovering energy from waste as a result of its processing.

Given the above, the aim of the study was set to identify concrete proposals for waste reduction in smart cities in line with the author's WM2GEG scheme. Concerning the above objective, two research hypotheses were formulated:

H1: Waste management focused on waste reduction benefits all components of the WM2GEG scheme.

H2: The use of modern methods of waste management significantly increases the aesthetics of the city.

A structured interview with representatives of selected cities identified as smart was used as the primary research method. Due to geographical distance and different time zones, the main form of contact was via e-mail or the official website of the territorial unit. The interview questionnaire in the electronic version was sent to mayors of the cities ranked in the top 60 of the Smart City Index 2020.

The survey was conducted between June 15, 2021, and July 31, 2021. The survey consisted of two stages, briefly referred to as mailing (stage 1) and data processing (stage 2). The mailing stage consisted of the following activities: selection of intelligent cities, preparation of a set of questions, finding an optimal form of contact to representatives of individual cities, and mailing the questions. The second stage consisted of collecting the answers, carefully reading their content, sending thank-you notes, and processing the data received.

It was decided to contact 60 cities ranked between 1 and 60 in the global Smart City Index 2020 (2021). These cities are Singapore, Helsinki, Zurich, Auckland, Oslo, Copenhagen, Geneva, Taipei City, Amsterdam, New York, Munich, Washington, Düsseldorf, Brisbane, London, Stockholm, Manchester, Sydney, Vancouver, Melbourne, Montreal, Hamburg, Newcastle, Bilbao, Vienna, Los Angeles, San Francisco, The Hague, Rotterdam, Toronto, Gothenburg, Hongkong, Hannover, Dublin, Denver, Boston, Seattle, Berlin, Phoenix, Birmingham, Chicago, Abu Dhabi, Dubai, Prague, Madrid, Busan, Seoul, Zaragoza, Barcelona, Tel Aviv, Lyon, Philadelphia, Riyadh, Kuala Lumpur, Warsaw, Moscow, Ankara, Krakow, Tallinn, and Brussels. Communication took place in three languages: English (52 cities), Polish (2 cities), and German (6 cities). Questions were addressed to the mayors of each city. The official websites were used to find information about the current president/mayor. Then, using the search engine www.google.pl and the websites www.linkedin.com and www.facebook.com, the e-mail addresses of 49 mayors were found. In the case of the remaining 11 smart cities, no direct e-mails to the city mayors were found, so questions were sent via the contact form available on the official city website.

The following questions about the waste management process were sent to the city authorities:

1. What is the waste collection process (households)?
2. How often is garbage collected from residents?
3. Do the residents segregate rubbish?
4. Is rubbish recycled (if so what types of rubbish)?
5. What happens to the mixed waste?
6. How do you fight plastic? Are there any regulations in line with the zero waste concept in the city of ..., e.g. restrictions on the use of plastic packaging?
7. Have you introduced any special programs in accordance with the zero-waste concept in your city, reducing the amount of energy and waste (e.g. subsidies, programs informing residents about the need to select rubbish, etc.)?

The main focus of the survey was related to waste management. However, questions were also asked about electricity consumption (question 1 and partly question 4). This was due to the strong link between the process of obtaining electrical energy and the generation of waste. This is especially true for energy extraction from fossil resources. The questions about energy were, therefore, a kind of motivator to develop the topic of waste creation in

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the urban space. In the case of the questions on rubbish, particular attention was paid to plastic, as this is what has contributed to such a drastically increasing amount of waste over recent years. In 2016, around 60 million tonnes of plastic were produced in European countries and as much as 335 million tonnes worldwide (Drzyzga & Prieto, 2019, p. 66). A significant proportion of these plastics become waste in a very short time.

The research was extended with a face-to-face interview with the owner of the odWAŻnik shop (http://odwaznik.com.pl/index.php/o-nas/) based in Warsaw, which aims to promote the concept of ZW. During the interview, she was asked about specific practices in line with ZW that can be used every day by residents of all territorial units, regardless of geolocation.

Results of the research

During the survey period, responses were received from 12 smart cities: Oslo, Copenhagen, Geneva, Taipei, Amsterdam, Düsseldorf, Brisbane, Bilbao, Vienna, the Hague, Hong Kong, and Warsaw. Responses were collected in MS Word. Due to the volume of material collected, it was necessary to select the most crucial information related to waste management. This information is presented in Table 2.

Table 2. Waste management in Smart Cities – examples

City/number in SCI2020 ranking	1. Is waste segregated and recycled? 2. What happens to mixed waste? 3. Selected solutions for reducing the amount of waste, energy consumption and waste management?
Oslo/5 (Norway)	1. Yes. 2. Mixed waste is incinerated with energy recovery. 3. a) Division of waste in optical sorters. b) Emphasis on the composting of organic waste. c) Action Plan to Reduce Plastic Pollution: by 2022, all use of unnecessary disposable plastic articles in Oslo will be phased out. d) Regular cleaning of beaches, fjords and waterways etc. e) Collaborate with research institutes to identify sources of microplastics dispersion on city waterways and the Oslo Fjord.
Copenhagen/6 (Denmark)	1. Yes. 2. Mixed waste is incinerated (the municipality of Copenhagen is the owner of all landfills and co-owner of the incineration plant). 3. a) Promote the setting up of photovoltaic installations and heat pumps. b) Ban on the use of disposable cups during festivals (from 2020 they can only be reusable). c) Exclusion of plastic bottles – tap water as still. d) Supporting the implementation at national level of the plastic packaging design manual. e) Tests of introducing self-propelled vehicles to the streets of the city.

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Geneva/7 (Switzerland)	1. Yes. 2. Mixed waste is incinerated. 3. a) The heat from incineration is used to generate electricity and is also used in a „remote heating system" that supplies hot water and heat to multi-apartment buildings in the city. b) It is forbidden to use disposable plastic dishes in public administration units
Taipei/8 (Taiwan)	1. Yes (kitchen waste is divided into 2 types: pig feed and other kitchen waste) 2. No information. 3. a) The ban on the use of disposable tableware by public institutions, private schools, department stores, hypermarkets, shops, restaurants and fast food chains. b) Reduction in consumption of PET, PS, PVC, PE, PP containers and plastic pallets and packaging boxes that are coated with vegetable fibers. c) Ban on the use of plastic carrier bags in 14 industries (including the public sector and shops). d) Promoting the Age-Friendly City concept in response to the rapidly progressing aging of the population. e) Promoting the collection of rainwater. f) Building alliances of smart cities „GO SMART" (international scale). g) „Love Taipei App" to check the time of garbage collection, the address of the collection points and the telephone number of nearby cleaning teams in order to arrange the direct collection of more rubbish. h) Promoting the installation of photovoltaic installations by public administration and households.
Amsterdam/9 (Netherlands)	1. Yes. 2. They are incinerated with energy recovery. 3. a) There are no disposable products at events (if they are: then with a deposit). b) Affiliation to the global nature fund of the Plastic Smart program.
Düsseldorf/13 (Germany)	1. Yes. 2. No information 3. a) Construction waste is used in processing plants. b) Sorting of waste (e.g. old clothes). c) Promoting the establishment of photovoltaic installations. d) Convenient mobile collections (e.g. of medicines). e) Emphasis on the composting of organic waste.
Brisbane/14 (Australia)	1. Yes (only 7% of the waste from the recycling bin is not suitable for recovery, it is sorted in sorting plants and sent to landfills). 2. Collected in landfills. 3. a) Lots of bins for waste (3 bins of 240 l). Garbage for recovery collected in containers (limitation of the number of bags). b) Strong emphasis on the composting of organic waste. c) Use landfill gas from landfills to produce energy. d) Act restricting plastics and other plastics: e.g. ban on the use of disposable tableware. e) Promoting the installation of photovoltaic installations. f) Constant improvement of education.
Bilbao/24 (Spain)	1. Yes. 2. The waste goes to the treatment plant. They are sorted (plastic, etc.) and the rest goes to an energy recovery plant. Then some of the waste is used in the cement industry. The remaining waste goes to a controlled landfill. 3. a) Cooperation with the non-profit organization Ecoembes (specializing in recycling) in the field of raising the awareness of residents about the use of plastic.

Vienna/25 (Austria)	1. Yes. 2. They are incinerated with heat recovery. 3. a) The waste residues (ash and slag) are freed from ferrous and non-ferrous metals and solidified, and then disposed of in an environmentally friendly manner in a landfill (approx. 30% by weight and approx. 10% by volume of the original material). b) Hazardous waste can be delivered at mobile collection points. c) Strong emphasis on composting. d) Possibility to rent reusable tableware. e) It is forbidden to use disposable dishes in public administration points and in the case of events exceeding 1 thousand. people. f) Out of oil and gas renovation campaign (aim: to facilitate the transition from fossil fuels to a sustainable heating system). g) Constant improvement of citizens' education.
Hague/28 (Netherlands)	1. Yes. 2. They are incinerated after separating the plastics and the cans. The heat generated is used to produce energy while metals are pulled from the ashes. 3. a) Creating a mini-station of underground waste containers (at least 1 / district) equipped with filling sensors (this limits the departures of garbage trucks). b) Possibility to arrange an online collection of bulky waste. c) Increasing the responsibility of companies producing plastic (they cover part of the costs related to the collection and processing of plastics).
Hong Kong/32 (Hong Kong)	1. Yes. 2. Mixed garbage is deposited in landfills. 3. Increasing the responsibility of companies producing plastic (they cover part of the costs related to the collection and processing of plastics).
Warsaw/55 (Poland)	1. Yes. 2. 80% of waste goes to MBP (mechanical – biological installations treatment of municipal waste); the remainder is burned. 3. a) Cyclical outdoor educational campaigns, such as the Zero Waste Fair, Eco-arranged. b) International Project "Capital Cities – capitals cooperating in the field of common challenges in hazardous waste management – Yerevan, Warsaw, Tirana. c) Promoting the setting up of photovoltaic installations and heat pumps through subsidies.

Source: authors' work.

As shown in Table 2, in all cities that actively participated in the survey (i.e. answered the questions sent electronically), waste is segregated and recycled. Initial segregation takes place directly in households. The following fractions are most often segregated: plastics, metals, glass, paper and cardboard, and bio-waste. Rubbish is collected by a special fleet of rubbish trucks directly from the residents' homes or designated points in the vicinity of their homes. Smart city citizens also have the option of bringing some of their waste (e.g. medicines, old clothes) to special collection points or using mobile collections. The remaining rubbish is collected from residents as mixed waste. In Oslo, Amsterdam, Düsseldorf, Brisbane, Bilbao, and Warsaw, waste undergoes additional checks at specialised sorting facilities. This sorting can be carried out both for garbage that has already been sorted (e.g. in Bris-

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bane) and in order to extract from mixed waste those fractions that can be recycled and that were mistakenly put in the mixed waste bin (Bilbao). As the Brisbane representative admits, from the mixed waste bin, only 7% is not recyclable. In Warsaw, mixed waste is sorted during mechanical-biological processing (MBP). This consists of crushing, screening, sorting, separation of ferrous and non-ferrous metals, etc., in order to select those fractions that are suitable for recovery.

Mixed waste after final sorting is, in most cases, incinerated with energy recovery (Oslo, Copenhagen, Geneva, Amsterdam, Vienna, the Hague, 20% of Warsaw's mixed waste is also incinerated) or sent to controlled landfills (Brisbane, Bilbao, Hong Kong). The City of Brisbane uses landfill gas for energy production – according to interview information, landfill gas can produce 46,000-megawatt-hours of electricity per year.

Table 2 also shows selected methods for reducing total rubbish in the cities participating in the study. Examples of such methods include:

- a ban on disposable plastic utensils (Oslo, Copenhagen, Geneva, Taipei, Brisbane, Vienna);
- introduction of a deposit for some plastic packaging (Amsterdam);
- possibility to rent reusable crockery during larger events (Vienna);
- plastic bag ban (Taipei);
- replacing bottled water with tap water (Copenhagen);
- promoting the installation of photovoltaic panels and heat pumps (Copenhagen, Taipei, Brisbane, Warsaw);
- composting of organic waste (Oslo, Düsseldorf, Brisbane, Vienna);
- cooperation with research institutions and other cities/countries to develop new solutions for waste reduction (Oslo, Taipei, Amsterdam, Bilbao, Warsaw)
- systematic raising of environmental awareness of the inhabitants (Vienna, Warsaw);
- introducing solutions which make it easier for residents to hand over their waste, e.g. mobile collections, apps for making waste collection appointments (Taipei, the Hague);
- making plastic companies more responsible (the Hague, Hong Kong);
- recycling of waste (all cities);
- use of waste for energy production through incineration or use of landfill gas (Oslo, Geneva, Amsterdam, Vienna, the Hague, Brisbane, Bilbao, Hong Kong).

Representatives of individual cities confirmed that creating plans to reduce the amount of waste in urban space and enforcing the positive behaviours and practices presented in the plan is a solution beneficial both for the ecosystem, as well as for the inhabitants and the city budget. Thus, after collecting and processing the data, the H1 verification was performed – waste

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management focused on waste reduction benefits all components of the WM2GEG scheme. This focused on the waste management methods listed above and the resulting benefits for all components of the WM2GEG scheme – for generations, for nature, and for profits.

The methods listed by the representatives of the individual smart cities aim to improve the environment by reducing waste, reusing waste, recycling suitable fractions, or using waste to produce energy. All technologies based on renewable energy sources are important here – photovoltaics, wind farms, heat pumps, or the creation of buildings with low energy consumption. Composting organic waste, which can further be used to feed crops in the form of natural compost, is also extremely beneficial for the environment.

The measures outlined above are also beneficial from an economic point of view. For example, the use of solar energy – apart from the initial installation cost – does not require an additional financial outlay from the residents. Additional savings can also be made by changing small daily habits – pouring tap water into a reusable bottle is much cheaper than buying water in a plastic bottle every day. In the long term, it is also cheaper to use reusable crockery at city events than to buy plastic cutlery and crockery every time. The municipality can also make significant savings if it has the right infrastructure to produce energy from waste incineration and use it to heat buildings in the city.

At the same time, in part of the smart cities section, the attention was drawn to the need to adjust the infrastructure related to waste management to the aesthetics of urban space and the convenience of its inhabitants. Examples of such solutions include mini stations of underground waste bins, sensors informing when the bins are full, equipping waste incinerators with special filters, specialised landfill sites as clusters of pathogens, or special applications for contacting residents with waste collection services.

The above examples fully support hypothesis H1 – waste management focused on waste reduction has a beneficial effect on all components of the WM2GEG scheme.

It then proceeded to verify H2 – The use of modern methods of waste management significantly increases the aesthetics of the city. A detailed waste management plan is in place in the cities covered by the study. Some of these types of plans are available online for citizens in the form of prospectuses or extensive brochures (e.g. Circular Copenhagen. Resource and Waste Management Plan 2024 in Copenhagen & Enveileder for plassering og valg av renovasjonslosninger in Oslo), and some in the form of guidelines and regulations which can be found after prior contact with a designated unit of the city or commune office. Representatives of the cities described unanimously admit that the creation of a waste management plan based on modern methods and technologies has significantly increased the level of the city's aesthetics.

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In this aspect, four main factors contributing to the enhancement of the city's aesthetics were identified:
1) introducing solutions resulting in the improvement of air quality in a smart city;
2) ensuring the appropriate number and form of bins and garbage containers in the city;
3) appropriate organisation of waste collection by designated services;
4) resignation or reduction of the number of landfills.

An example of activities related to the improvement of air quality is the use of renewable energy sources by companies and private households. Thanks to the use of solar or wind energy, and also thanks to the promotion of heat pump installations, waste resulting from the combustion of, e.g. coal, is significantly reduced. Electric cars are becoming more and more popular in the surveyed smart cities, and Copenhagen intends to conduct tests related to the introduction of self-propelled vehicles to the city streets. These innovations significantly reduce airborne waste that is not visible to the naked eye, such as CO_2. They also reduce the amount of dust and dirt that reduces the urban aesthetics.

Another factor concerns the proper number and form of rubbish containers. A well-thought-out arrangement of litter bins significantly reduces the amount of paper, plastic bottles or cans on the streets or in dedicated green areas. The mere adjustment of the number of baskets to the city's needs improves the aesthetics of the surroundings and increases the quality of life of the residents. The aesthetics is additionally enhanced by the use of modern technologies, such as underground garbage cans or sensors that indicate that the containers are full.

An important role is also played by the appropriate organisation of waste collection from private homes or public institutions. Setting specific and tailored to the needs of residents' waste collection hours means that unsightly bins or garbage bags are displayed in front of the property for a short time. Noteworthy are also applications, thanks to which residents can order a team responsible for the collection of, e.g. bulky waste, used, e.g. in Taipei.

An important factor is the replacement of traditional landfills with modern incinerators, existing in some of the smart cities studied: Oslo, Copenhagen, Geneva, Amsterdam, Vienna and The Hague. The combustion process is accompanied not only by the reduction of the amount of waste in the urban space but also by the recovery of energy used for the needs of the city and its residents. And the lack of traditional landfills significantly increases the aesthetics of the city and the comfort of the life of its inhabitants.

The practices and solutions described in the above paragraphs confirm H2. The use of modern methods of waste management significantly increases the aesthetics of the city. This benefits both the environment, society, and the

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budget of the territorial unit. The presented solutions are also largely 100% in line with the ZW hierarchy. The main differences are visible in the final stages of management – while most cities prefer incineration or landfilling of mixed waste, cleared of recyclable fractions, the current ZW hierarchy focuses mainly on excluding non-recyclable waste.

Most of the activities listed above can only be implemented by municipal authorities and special waste management support organisations. However, a number of practices can be applied by people interested in the concept of ZW. An example of such solutions is given by the owner of the Warsaw shop odWAŻnik, which promotes ZW activities. Actions of this type include using a reusable bag or sack for everyday shopping, buying vegetables and fruit in bulk, choosing cosmetics in glass, carrying water in a reusable bottle instead of buying bottled water, buying accessories made of ecological materials (e.g. a bamboo toothbrush), and giving cardboard boxes and parcel fillers back for reuse (e.g. to mail-order shops).

Conclusions

Smart cities 3.0 are ideal models for creating urban spaces in the 21st century. Thanks to a systematic approach to the management of individual elements of infrastructure, a focus on sustainable economic development, and environmentally friendly social and financial solutions, smart cities can serve as an example for other centres of the population.

The process of rational waste management in urban space can be reduced to three general commands: plan, apply, and motivate! However, only the appropriate execution of these commands gives a chance to manage waste in accordance with the WM2GEG scheme. The creation of a plan tailored to the needs of the city and its inhabitants was identified as an initial stage in the process of rational waste management.

After the plan is prepared, the waste reduction methods indicated in the plan should be applied. The study identified a number of waste management methods in smart cities 3.0. The most important of these include low-energy buildings, renewable energy, reduction of plastic production, smart rubbish containers integrated into the urban landscape and equipped with sensors indicating when they are full, specialised rubbish sorting, public education campaigns on the need to act ecologically, applications enabling citizens to contact waste disposal services, and the treatment of non-recyclable rubbish combined with energy recovery. Based on interviews with representatives of specific smart cities, it was shown that waste management focused on waste reduction has a positive impact on all components of the WM2GEG scheme, which include society ('for a generation'), environment ('for the environment'), and economic benefits ('for gains'). The representatives of the cities studied also confirmed that the use of modern methods of waste management significantly increases the aesthetics of the city.

The key step is to motivate residents to apply the desired practices in the waste management process. The primary forms of motivation identified during the study are: educating residents from an early age in the field of responsible waste management, conducting social campaigns promoting behaviours that reduce the amount of waste and strengthening private businesses and initiatives related to promoting Zero Waste behaviour. The article presents examples of solutions in accordance with the ZW available to all city residents, such as the use of reusable bags, resignation from purchasing bottled water in favour of a reusable water bottle, or changing consumer habits (e.g. choosing loose fruit and vegetables, without additional foil nets and bags).

The article also presents ZW-compliant solutions available to all city dwellers, such as the use of reusable bags, abandoning the bottled water purchase in favour of a reusable bottle, or changing consumer habits (e.g. choosing fruit and vegetables in bulk, without extra plastic nets and bags).

From a holistic point of view, creating an urban infrastructure that is 100% compatible with the zero waste concept is very difficult (Zaman & Lehmann, 2011, p. 177). At the moment, most attempts to recover rubbish leave some waste. Therefore, it seems essential to carry out further research towards improving waste management systems and introducing appropriate recommendations for administrations, companies, and individual consumers related to sustainable consumption. At the same time, it is important to periodically check the level of public awareness of the danger posed by waste that is growing too fast and ensure that citizens are systematically educated in this area. Perhaps it is also worth considering whether today's reality in any city in the world really includes entirely zero waste activities? Are the examples of rational waste management indicated in the paper not yet an element of the less waste strategy, which may be interpreted as a kind of introduction to the ideal state of zero waste?

Another aspect worth exploring is whether innovative technological solutions that reduce rubbish and urban pollution today will result in a sharp increase in waste in the future. For example, electric cars are considered environmentally friendly solutions, especially when combined with renewable energy sources. However, it would already be worthwhile to test the recyclability of electric motors in individual urban centres. The same goes for photovoltaics – using renewable solar energy is very beneficial for the environment. However, cities must be prepared for a sharp increase in waste in the form of used photovoltaic panels over the next few to several dozen years.

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The contribution of the authors

Dorota Jelonek – 50% (conception, data analysis, interpretation, discussion).
Dorota Walentek – 50% (literature review, acquisition of data, data analysis).

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