Smart Waste Management Survey: Comparison of needs and challenges in three different sized northern cities

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ABSTRACT

Effective waste management is an essential service and a challenging task for any city. The aim of this study is to collect information from stakeholders of three different sized northern cities and identify the current status, main needs and challenges of waste management in a city context. The work adopts a survey-based research method. Surveys for service consumers (i.e., residents) and service providers (i.e., authorities and companies) were carried out in Helsinki, Lappeenranta (Finland), and St. Petersburg (Russia), additionally surveys for service providers (i.e., authorities and companies) were carried out in Helsinki. The surveys focused on household waste sorting and urban waste management, waste management logistics, waste management in public places (i.e., parks and recreational areas), and new technologies in waste management. We identified needs and challenges of waste management in each of the 3 cities. We also analyzed the possible causes of the identified challenges based on additional comments from the respondents and compared the results in the different cities with each other. It was found that common problem areas are sorting of multiple waste types, logistics, and maintenance of cleanliness in public spaces. Based on the survey results we created general guidelines utilizing IoT and other technological solutions that can be adopted for tackling different waste management challenges. These guidelines can be used by city authorities and other stakeholders engaged in waste management activities.

CCS CONCEPTS

• **Surveys and overviews**; • **Multi-criterion optimization and decision-making**;

KEYWORDS

Waste management, Survey, Waste collection, Waste sorting, IoT

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1 INTRODUCTION

Effective waste management is an essential service and a challenging task for any city. Waste management (WM) includes waste collection, waste sorting, logistics, and recycling, and the outcome of effective WM is seen as clean streets and park areas. Each of the operation areas has its own specific problems and challenges. For example, waste sorting requires coherent guidelines to enable citizens to sort the garbage correctly and the relevant infrastructure (points for separate waste equipped with appropriate containers) to allow citizens to follow the guidelines. Waste logistics requires the necessary infrastructure (properly equipped waste trucks and waste collection points, waste collection areas) and good logistics management (schedules, on-demand emptying of waste bins, operations considering city traffic, and reliable statistics for operations planning) so that environmental aspects (emissions and air quality, traffic noise) can be properly considered. As a consequence, effective waste management requires the participation of many relevant stakeholders [1]: waste collectors (waste truck drivers and janitors), managers (dispatchers), civic authorities (government, city administration, municipality, waste department), citizens, waste disposal services, waste recycling organizations, waste collection area owners and operators, as well as a number of secondary (indirectly affected) stakeholders.

This study is a continuation of our previous study [1] on 1) identified the main approaches and services that are applied in the city and smart garbage bin (SGB)-level SWM systems, 2) listed sensors and actuators and analyzed their application in various types of SWM systems, 3) listed the direct and indirect stakeholders of the SWM systems, 4) identified the types of data shared between the SWM systems and stakeholders, and 5) identified the main promising directions and research gaps in the field of SWM systems. One of the identified research gaps was the absence of a general holistic view at any level of operation. In the presence of a large number of studies describing individual aspects of the design, development,

implementation of SWM systems in various locations to solve various problems, there is no general description that would unite all the accumulated results at any level of operation. So, there is a need in decision support (DS) framework, that could provide recommendations about WM in the city, based on current tasks, the characteristics of the city and city context.

This study is focuses on residents, authorities and companies involved in the waste collection and removal process as the main stakeholders. In the work, we use a survey as our research method. Surveys for service consumers (i.e., residents) were carried out in Helsinki, Lappeenranta (Finland), and St. Petersburg (Russia), and surveys for service providers (i.e., authorities and companies) were carried out only in Helsinki as a part of the 'Cross-Border Dimensions of Disruptive Information Technologies'[1] (CroBoDDIT) project. The CroBoDDIT project aims to promote the development of disruptive information and communications technology (ICT) solutions for urban infrastructures (e.g., waste management) by utilizing the expertise of local companies. The aim of this study is to collect information from stakeholders in three different sized northern cities and to identify the current status and main challenges of waste management in a city context. The objectives of the study were: 1) to find common problems in the field of waste management for studied northern cities, 2) to find problems specific to each city and to suggest the causes of their occurrence, 3) to write a description of the city context, which can later be used in the knowledge base of the DS framework, and 4) to propose modern technological solutions to the identified problems based on the data collected in [1] and the expert's knowledge (data, collected through surveys of service providers), taking into account the needs of service consumers. The studied cities, utilize various strategies in waste management, differ in use of new technologies and infrastructures, and environmental awareness of the population differs considerably. This allowed us to study various approaches to waste management in various contexts and link the results to the approaches and to the attitude of the population.

The remainder of the paper is organized as follows: Section 2 describes related work in the area of WM surveys, Section 3 describes the research methodology followed in the study, Section 4 presents the results of the surveys, Section 5 discusses and analyzes these results, and Section 6 concludes the paper by restating key aspects of the study and indicating future work.

2 RELATED WORK

Questions related to WM are an integral part of many national citizen surveys [2], [3], [4] and citizen satisfaction studies [5]. These surveys have also examined views on the quality of garbage collection, garbage sorting habits, existing problems with waste management, and the need for new services [6]. Additionally, the results of such surveys have formed the basis for analyses in scientific papers.

In the related papers reviewed, it was noted that the surveys examined, for example, waste sorting and environmental awareness, citizens' habits and behavior, consumers' participation in waste reduction and recycling, consumers' willingness to pay for waste recycling, problems in WM in a particular region or country, as well as digitalization efforts and strategies of service providers. A summary of key survey-based works related to WM is provided in Appendix. All the surveys listed were online questionnaire-based, as was the one we conducted as part of the study described in this article. Based on the studied papers, we compiled a holistic view that connects these topics.

Waste sorting and environmental awareness are key aspects of most of the surveys. Citizen awareness is studied in [7], among other factors, and the authors conclude that it is the main factor affecting citizen participation in waste reduction and recycling. In [8], the level of awareness about the environmental and health hazards associated with unsystematic management of solid waste is studied in the context of people's willingness to participate in a WM program. Identified problems include collection schedules not being adhered to by collectors, disorderly disposal, and ineffective waste minimization services (no reuse, recycle, and composting). In [9], the authors conclude that awareness about the environment and recycling is one of the key factors influencing consumers' willingness to pay for e-waste recycling. This once again confirms that raising citizens' awareness is a key aspect in increasing their motivation and participation. In [10], the authors study the reason for low environmental awareness among young consumers. According to the study, the reason for low environmental awareness among young consumers is the absence of education and publicity for environmental issues and sustainable e-WM practices in China. The work of Ferronato [11] also considers young consumers. The authors study waste sorting and ecological awareness, knowledge and behavior of students in two Italian universities. According to the study, the main issues associated with municipal solid waste (MSW) sorting and disposal are public awareness and attitudes towards current collection and management activities.

Another important aspect of WM is **citizens' habits and behavior**. The work in [9] studies consumers' behavior, among other factors, and how it influences consumers' willingness to pay for e-waste recycling. Various aspects of citizens' habits and behavior are explored in [12], for example, behavior as regards the management of domestic waste fractions, personal involvement in separating home waste fractions, and daily habits with respect to the use of disposable objects for groceries. Students' waste sorting and recycling habits are studied in [11]. All the studies emphasize that environmental awareness is a key aspect in effective waste management.

Several of the papers study factors affecting **consumers' participation in waste reduction, recycling** [7] and **sustainable e-WM practices** [9], [10]. The most important factors affecting consumers' participation in waste reduction and recycling are: 1) citizens' environmental awareness [7], [9]; 2) education level [9], [10], 3) monthly income [9]; and 4) publicity for environmental issues and sustainable WM practices [10].

Some papers investigate the influence of various factors on **consumers' willingness to pay for waste recycling** [7], [9]. In [7], the authors conclude that the key factor is citizen awareness, followed by social motivation. The work presented in [9] focuses on e-waste recycling and the following main factors are identified: environmental awareness, monthly income and education level.

[1] CroBoDDIT project, https://forumvirium.fi/croboddit-disruptiivisten-teknologioiden-kehittamista-urbaaneissa-infrastruktuureissa-alueellisten-yritysten-osaamista-hyodyntaen/

Several surveys have been carried out to identify the main problems in **WM in a particular region or country**. For example, [13] examines pollution prevention and WM issues in New Zealand. The work focuses on the causes of these problems, and various solutions are proposed. The work in [11] investigates issues related to municipal solid waste (MSW) in Italy based on behavior analysis of students' waste sorting practices, ecological awareness, and knowledge.

Digitalization efforts and strategies of service providers (WM firms) are investigated in [14]. The work considers levels of digitalization, steps in the WM value chain, and objectives, approaches, and transformational measures for digitalization. The authors suggest so far largely ignored research opportunities and present recommendations for WM firms and associations.

Thus, based on the findings of previous research, the key elements influencing the involvement of residents in various activities related to smart WM are ***waste sorting awareness*** and ***environmental awareness***. These factors influence residents' habits and behavior, the involvement of residents in waste sorting, reduction and recycling, and in some cases even motivate them to pay for the implementation of these services. Awareness is influenced by education level, publicity for environmental issues, and WM practices.

3 MATERIAL AND METHODS

A survey is used to collect information about WM problems and needs in northern cities. The survey approach was chosen as it allowed us to reach a larger number of respondents and collect more comprehensive data.

Our study aims to answer the following research questions (RQs):

RQ 1: What is the current status, city context, what are the main challenges and needs of WM in the studied northern cities from the point of view of service consumers (i.e., eco-aware residents) and service providers (i.e., authorities and companies)?

RQ 2: How can IoT or other technical solutions be used to improve WM in the city?

3.1 Survey Context

To obtain more reliable and widely applicable results, surveys were conducted in three cities of different sizes, each with different infrastructure and different levels of environmental awareness amongst residents. The profiles of the selected cities are as follows.

Lappeenranta: small city (area: 758 km^2, population: 72 409[2]) with a good ecological situation, which is confirmed by the fact that Lappeenranta won the title of the European Green Leaf Award 2021 [15] in a competition organized by the European Commission, a developed WM and recycling infrastructure, and widespread sorting of at least 7 different types of waste. Developed infrastructure refers to the presence of separate waste collection points in the yard of each house, as well as the availability of infrastructure for recycling and waste disposal. Finnish waste legislation is largely based on EU legislation, but in some cases includes stricter standards and limits than those applied in the EU as a whole [16].

Helsinki: medium-sized city (area: 213,8 km^2, population: 661 6552) with a fairly good environmental situation according to Helsinki Region Environmental Services (HSY), a developed WM and recycling infrastructure, widespread introduction of new technologies [17], and widespread sorting of at least 7 different types of waste.

St. Petersburg: large city (area: 1,439 km^2, population: 5 351 935) with a very poor environmental situation, a waste collection and sorting infrastructure that allows sorting of 3 types of waste in the city center, and low environmental awareness among the majority of the population.

3.2 Survey design and tools

The study focuses on consumers (residents) and producers of the services (civic authorities and companies involved in waste collection and removal) as the main stakeholders. Although the answers to the survey represent individual perceptions to the topic, the social dimension is included into these answers through social norms these individuals follow. Covering the social dimension in a holistic manner is out of the scope of this paper. Thus, two questionnaires were developed: (1) for residents, and (2) for representatives of the city authorities and employees of companies associated with the management of solid waste.

The questionnaires considered 4 topics: household waste sorting and urban waste management, WM logistics, WM in public places (i.e., parks and recreational areas), and new technologies in waste management. The list of survey questions for Lappeenranta[3] and St. Petersburg[4] differ in language and minor details, reflecting the differing city context. The questionnaires contained both open-ended and closed-ended questions but only answers to closed-ended questions were required.

Self-administered online questions based on Google Forms were used to conduct the surveys. Links to the surveys were posted in groups on social networks of the city in which the survey was conducted. The duration of the survey was set to 2 months, but the duration was adjusted based on the number of responses: from September to November 2020 for Helsinki, from May to June 2021 for Lappeenranta, June to September 2021 for Saint-Petersburg. If it was not possible to collect the minimum required number of responses during the specified period (20 for Lappeenranta, 50 for St. Petersburg and Helsinki), the link to the survey was posted again, and the timing of the survey was extended.

Analysis of answers to closed-ended questions were carried out using Google Forms and Excel. Analysis of answers to open-ended questions and additional comments was done partly manually by categorization and counting the number of answers in each category, after which further analysis was carried out using Excel.

4 RESULTS

In this section, we will describe the composition and profile of the respondents, assess their habits regarding waste sorting, and describe the current trends and needs in each of the areas under consideration: household waste sorting and urban waste management, WM logistics, and WM in public areas. We will also describe the

[2] stat.fi, Statistics Finland's free-of-charge statistical databases, https://statfin.stat.fi/PxWeb/pxweb/en/StatFin/StatFin__vamuu/statfin_vamuu_pxt_11lj.px/

[3] Lappeenranta citizens survey questions: https://docs.google.com/forms/d/e/1FAIpQLSfmwjAm4vrbutV02yIk_D2NoBybnuejfqYCKPRADVPbEPuzgg/closedform

[4] St. Petersburg citizens survey questions: https://docs.google.com/forms/d/e/1FAIpQLSeRcgd2aeOJHYvzRvP79p2E8VzBpm00uoKLm1U1HQI6ht7RNw/closedform

Table 1: Sample sizes, Confidence Level and Margin of Error for the samples of service consumers

City	Population size	Margin of Error	Population Proportion	Confidence Level (z-score)	Sample size
Helsinki	661 655	7.42%	56%	90% (1.65)	122
Lappeenranta	72409	17.1%	56%	90% (1.65)	23
St. Petersburg	5 351 935	6.9 %	11%	90% (1.65)	56

level of awareness of respondents from the different cities about new technologies. For Helsinki, we will assess trends and problems based on an analysis of the responses of the two groups of respondents: consumers (residents) and producers of the services (civic authorities, companies involved in the waste collection and removal process). For Lappeenranta and St. Petersburg, this analysis is done based only on consumers' survey results due to the lack of responses from service providers.

4.1 Sample sizes, representativeness, validity and study limitations

Surveys for service consumers were targeted at environmentally aware and environmentally active people. Estimated time to complete the survey ranged from 20 minutes (answers to mandatory questions marked with "*" only) to 40 minutes (answers to all questions, including optional open-ended questions). This approach allowed us to get a more comprehensive understanding of the object of study, but significantly reduced the number of respondents who completed the questionnaires. So the sample sizes for service consumers in the different cities are associated with the city population and the level of environmental awareness of the citizens. To confirm the representativeness and validity of the available samples, we used formula (1). We based the Population Proportion on percentage of environmentally aware and active people in each city, which, based on official statistics, was 56% [18] for Helsinki and Lappeenranta, and 11% [19] for St. Petersburg.

$$S = \frac{\frac{z^2 * p(1-p)}{e^2}}{1 + \left(\frac{z^2 * p(1-p)}{e^2 N}\right)} \quad (1)$$

where S = sample size; N = population size; e = Margin of error, z = z-score; p = population proportion.

The study involved 122 respondents among city residents and 22 among representatives of authorities and companies in Helsinki; 23 respondents among city residents and 1 among representatives of authorities and companies in Lappeenranta; 56 respondents among city residents and 1 among representatives of authorities and companies in St. Petersburg. Based on statistical analyses of the samples (Table 1), we conclude that 122 surveys are representative for Helsinki with confidence level of 90% within ±7.42% of the surveyed value; 56 surveys are representative for St. Petersburg with confidence level of 90% within ±6.9% of the surveyed value. However, the main limitation of our study was the sample size for Lappeenranta, that has a margin of error 17.1% with confidence level of 90%. However, based on the analysis of the answers of respondents from Lappeenranta to additional open questions, we concluded that the accuracy (bias) and precision (variance) of the study is quite high. We requested data on the number of "waste management experts (in terms of new technologies, IoT devices, data analysis) who are employees of companies working in the field of garbage collection and recycling" in Helsinki region from HSY, STAT.FI (official Finnish statistics) and Finnish Ministry of the Environment; but no such statistics exist. Therefore, we consider a sample size of 22 experts (among representatives of authorities and companies in Helsinki) to be valid based on [20].

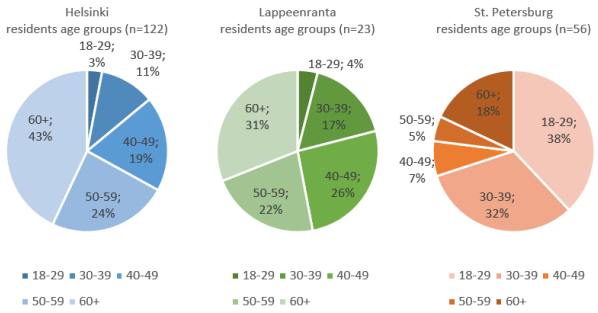

Figure 1: Residents age groups

4.2 Demographics of the respondents

The demographics of the respondents are shown in Figure 1.

Among the 122 residents of Helsinki who took part in the survey, the largest percentage were residents of older age. A similar pattern was observed among the inhabitants of Lappeenranta, but the distribution was more even. In St. Petersburg, however, the distribution turned out to be the opposite: the largest percentage of respondents were young people. Thus, we can conclude that older people are most interested in the problems of ecology and separate collection of solid waste in Helsinki and Lappeenranta, whereas in St. Petersburg, the younger generation is mainly interested in such problems. However, it should be taken into account that links to surveys in the different cities were delivered to respondents in different ways, which could affect the sample of respondents.

4.3 Household waste sorting habits

In this section we asked if the residents sort their waste, and if yes, what types of waste they sort. At this point, it should be kept in mind that people who are already sufficiently interested in the subject matter, answered the survey, i.e., it was assumed that the survey would initially be answered by people already sorting garbage.

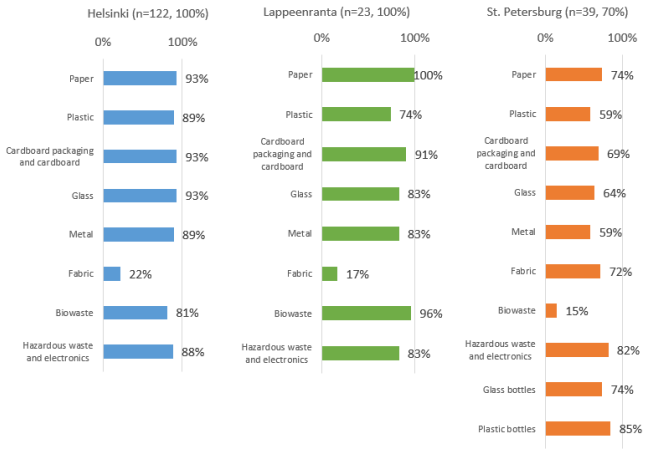

Figure 2: Responses to the question: "Which waste do you sort?" (Answers from people who said they sort waste)

In Helsinki and Lappeenranta 100% of respondents answered that they sort household waste. However, 30% of the survey participants from St. Petersburg answered that they do not sort any type of waste. We included a clarifying question for St. Petersburg residents: "If you don't sort waste, why?". Most of the answers indicate that people do not have information about where in their area it is possible to dispose of sorted garbage. Other popular answers to the question of why people do not sort waste were "I do not get the point of it" and "I have no information on how to properly sort waste". Based on these responses, we concluded that the current situation does not enable even fairly environmentally aware St. Petersburgers to dispose of sorted garbage.

In addition, we asked what types of waste are being sorted by the respondents (Figure 2). For St. Petersburg, we added two additional types of waste "glass bottles" and "plastic bottles", since there are collection points for glass and plastic bottles in many parts of the city.

Approximately the same percentage of respondents sort hazardous waste in all three cities: 88% in Helsinki, 83% in Lappeenranta and 82% in St. Petersburg. Almost all respondents from Lappeenranta (96%) and Helsinki (81%) sort bio-waste, but only 15% in St. Petersburg. Based on additional explanations from respondents from St. Petersburg, this is due to the lack of containers for biowaste. However, St. Petersburgers sort and recycle fabric more actively than respondents from the other cities (72% versus 17–22%). 100% of the residents of Lappeenrata, 93% of the residents of Helsinki but only 74% of the residents of Petersburgh recycle paper. Apparently, this is also due to a lack of information and citizen awareness. The rest of the garbage types are sorted and recycled at approximately the same level in the three cities: 89–93% in Helsinki, 74–91% in Lappeenranta, and 59–85% in St. Petersburg.

4.4 General assessment of waste management in the cities studied

We asked respondents to rate on a five-point scale how well household WM works in the city, what areas are handled most successfully, and which need to be improved. Citizens' assessments of the

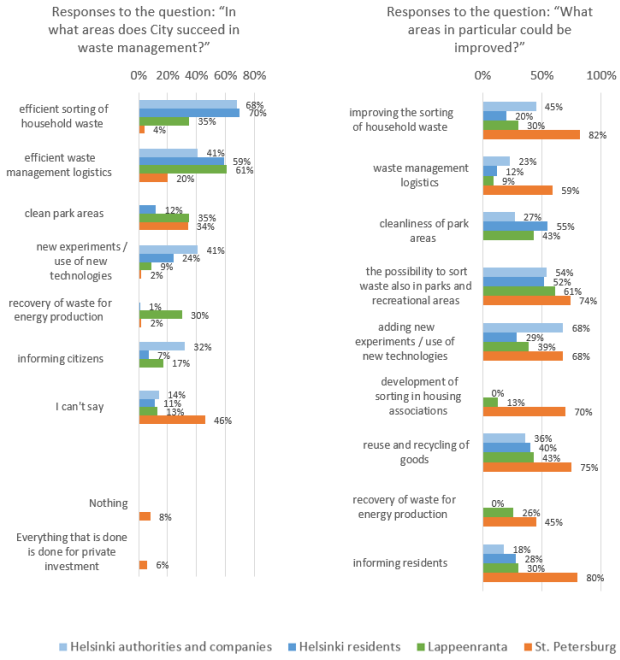

Figure 3: In what areas does City succeed in WM and what areas in particular could be improved?

city's success in household WM in Helsinki and Lappeenranta are quite similar. Most residents believe that the city is coping well with the task of waste management. The assessments of representatives of civic authorities and WM companies in Helsinki roughly coincide with the assessments of citizens, but opinions are slightly more negative. We believe that this is due to better awareness of existing problems. In St. Petersburg, the situation is the opposite; most of the respondents believe that household WM is not working very well or is handled poorly.

Next we asked respondents in what areas each city succeeds in WM and what areas could be improved (Figure 3)? In Lappeenranta and Helsinki, the situation is quite similar. However, in Lappeenranta, only 35% of the respondents believe that waste sorting works efficiently. The residents of Lappeenranta are more satisfied with the cleanliness of parks than the residents of Helsinki. The main needs expressed by residents of both cities are clean park areas and the ability to sort waste in parks. A further need in both cities is improvements to the reuse and recycling of goods. Based on the data, it can be concluded that the ecological situation in Finland is quite good and WM in general solves priority tasks, therefore people give priority to improvements related to parks and reuse and recycling of goods. There are also minor differences in the assessment of the city's achievements in conducting new experiments and using new technologies. This result is due to significantly more new experiments being carried out in Helsinki. Lappeenranta residents are more concerned about recovery of waste for energy production.

Based on respondents' answers to open-ended questions on this topic, the main problems noted by the residents of Lappeenranta are: 1) impossibility of sorting fabric separately; and 2) no containers for all the different types of garbage in some housing associations.

The main problems noted by the residents of Helsinki in additional comments are: 1) sorting problems – (i) in some housing associations it is not possible to sort all types, and (ii) in a small kitchen it is inconvenient to sort all types of garbage; 2) logistics – (i) different types of garbage are collected by different companies, and (ii) traffic congestion due to garbage trucks); 3) poor cleanliness of the area around waste containers; 4) overflow of waste containers; 5) impossibility of sorting fabrics separately; and 6) lack of information on – (i) points for separate collection of some types of waste, and (ii) the rules for waste sorting. Helsinki residents believe that more types of waste need to be sorted and recycled, which is an opinion shared by respondents from civic authorities and companies involved in waste management.

In additional comments, respondents from Helsinki expressed a need for improvements in WM in parks in the following areas: (i) combatting the problem of birds scattering garbage, (ii) addressing the problem of discarded face masks, (iii) increasing the number or size of bins, (iv) improving the frequency of garbage collection, and (v) enabling sorting of some types of waste in parks (for example, biowaste). Another important area, in the opinion of respondents, is sorting and recycling, specifically, sorting fabrics and electronics, making it easier to sort waste at home, and simplifying waste recycling. The problem of cleanliness of waste collection areas in some housing associations also requires a solution. In addition, we received comments on the need to inform residents about the schedule of garbage trucks.

Residents and representatives of WM authorities and companies in Helsinki presented quite similar assessments, which suggests that residents are well informed, and that the authorities understand the current situation. However, authorities and companies gave a higher evaluation to the areas of citizen information and new experiments than residents, while at the same time considering that these areas are more in need of additional improvements.

In St. Petersburg, the situation is radically different from Finland. The most popular answer to the question "In what areas does the city succeed in waste management?" was "I can't tell". However, residents noted clean park areas and efficient logistics. In additional comments, some of the respondents indicated that there are no successful areas, and some that all initiatives for waste collection of separated waste are carried out by activists for private donations and are not funded from the city budget. Among the areas that require improvement, the respondents noted almost all the proposed options. The most popular responses were waste sorting and citizen information. On this basis, and taking into account the comments of the respondents, we concluded that: 1) there are big problems in fundamental areas of WM and the process of separate collection of waste fractions, and 2) waste recycling is organized rather poorly at the moment.

From the explanatory comments of the respondents from St. Petersburg, we concluded further that residents' assessments are associated with: 1) inaccessibility and the small number of containers for separate waste collection, 2) an inability to sort many types of waste (for example, bio-waste), and 3) overfilled bins that are not properly sorted (for example, there is a lot of non-bottle plastic waste in plastic bottle bins). These problems are all associated with logistics and citizen awareness.

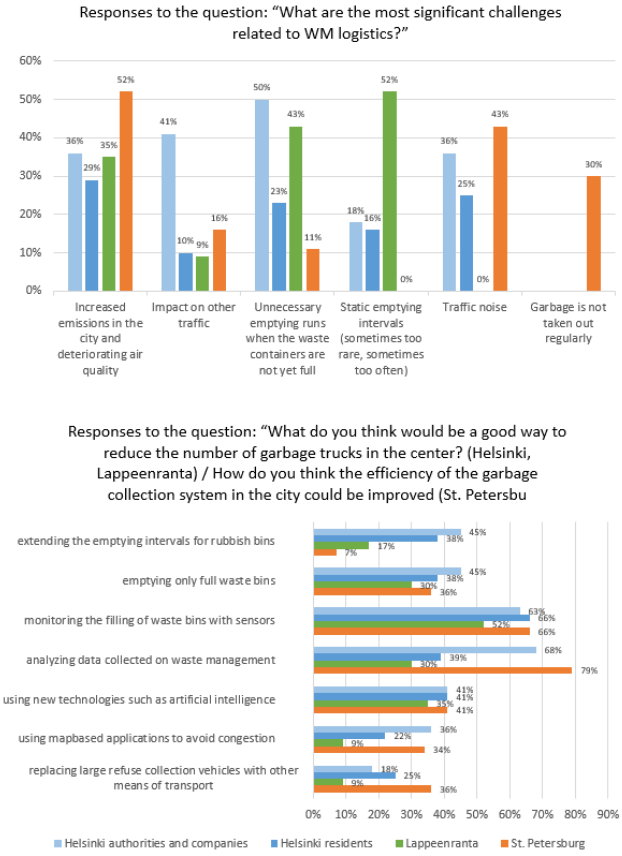

Figure 4: Waste Management logistics

4.5 Waste logistics management

In this section of the survey, we investigated problems related to waste logistics. First, we asked about the main problems in the field of waste logistics (Figure 4). Additionally, we asked respondents how these problems could be solved. The aim was better understanding of the attitude of respondents to existing problems and various new technologies.

Residents of all cities are concerned about emissions and air quality. For residents of St. Petersburg, this is the biggest problem. Also, many residents of St. Petersburg complain about traffic noise, which is related to St. Petersburg being a very large city with a difficult ecological situation. Interestingly, 30% of respondents from St. Petersburg selected an additional answer: "Garbage is not taken out regularly".

For Lappeenranta residents, the main problems are static emptying intervals (sometimes too rare, sometimes too often), unnecessary waste collection trips and emissions.

According to Helsinki residents, the main problems are emissions and unnecessary waste collection trips, and as it is a large city, there is also a problem of traffic noise. Representatives of WM companies and authorities, along with these problems, also note the negative impact of garbage trucks on the rest of city traffic and

consider the problem of unnecessary emptying runs to be more serious. This differing view can be explained by WM operators seeing the big picture and being more informed than residents. Based on respondents' answers to open-ended questions on this topic, the problem of the schedules of garbage trucks was also noted and a recommendation was given not to collect garbage during rush hours, but at night and early in the morning. Poor placement of some garbage containers was also highlighted, which creates traffic congestion and makes it difficult for pedestrians and cyclists to pass.

We also asked Finnish respondents what would be a good way to reduce the number of garbage trucks in the center of the cities. Russian respondents were asked how the efficiency of the garbage collection system in the city could be improved. The questions are a bit different because of differences between the countries (Figure 5). The different wording of the question could slightly affect the results.

Respondents in all cities chose to use new technologies. Based on the responses received, we draw conclusions only about the residents' technical awareness. In St. Petersburg, the option of analyzing data on the waste collection process was popular. In Helsinki and Lappeenranta, more respondents choose the option "monitoring the filling of waste bins with sensors". In our opinion, this is because some types of garbage in Finland are collected too frequently, and this is a problem. Representatives of authorities and companies gave similar answers to residents but noted that the analysis of WM data is the most important aspect in solving the logistics problem. In addition, it was proposed to adjust the schedule of garbage trucks (for example, to collect garbage only at night and in the early morning) and use garbage cans with a larger capacity.

4.6 WM in parks and recreation areas

We asked open-ended questions about specific problems and possible solutions in the area of WM in parks and how, in the opinion of the respondents, they should be solved. Many respondents gave detailed answers, describing several problems at once or ways to solve them. We received the largest number of complaints from the residents of St. Petersburg. All the main problems listed are related to the ineffective work of the responsible authorities, often this was even indicated directly in the comments of the respondents: there are too few trash bins, they are overflowing, garbage is collected irregularly, and park area cleaning is of poor quality. The best situation is in Lappeenranta, where people complain about birds carrying garbage and inconsiderate citizens throwing garbage past the trash can. The main problem in Helsinki is overflowing trash cans, i.e., problems with logistics and timing of garbage collection. Many respondents also mentioned the lack of waste sorting in parks as one of the main problems.

4.7 Use of new technologies

We asked respondents which modern technologies they know, is there a need to use technologies in waste management, and which new services and technologies should be offered as a part of waste management. We found out that the level of citizens' awareness of new technologies in St. Petersburg is slightly higher than in Helsinki

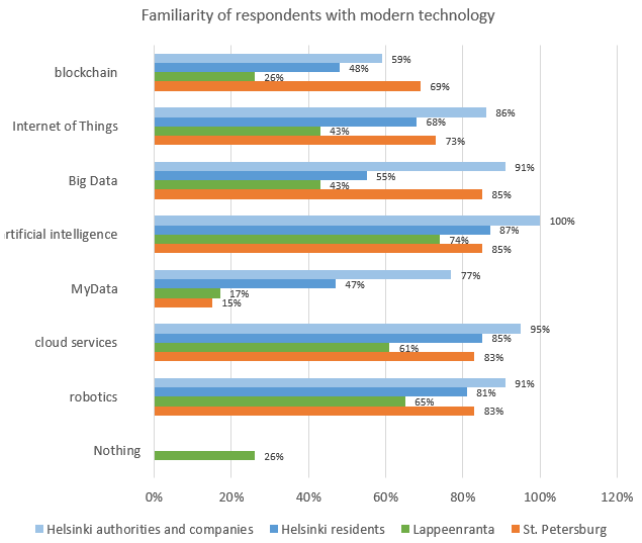

Figure 5: Familiarity of respondents with modern technology

and much higher than in Lappeenranta (Figure 5). Lappeenranta is a rather small city, in which there are not many experiments with new technologies, which might account for the difference. Also, in Finland (especially in Lappeenranta), most of the respondents were older.

Technologies such as AI, cloud services and robotics are familiar to most of the respondents from all the cities. The rest of the technologies are more familiar to residents of the larger cities (Helsinki and St. Petersburg) than residents of Lappeenranta. The exception is MyData[5], which is known only by the residents of Helsinki. As expected, representatives of the authorities and companies in Helsinki are much better informed about technology than residents, which may partly explain the difference in responses about new services and technologies that could be offered as part of waste management. Most of the respondents fully or partially agreed that new technologies should be used more in WM.

We also asked what new services or technologies should be offered as part of WM (Figure 6). This question was asked of both service providers and consumers. Based on the answers to this question, we were able to better understand consumers' level of technological awareness and attitude towards the introduction of new technologies and services. Responses from service providers were taken into account when issuing recommendations on the introduction of new services to solve the identified problems.

The most popular residents' responses in Helsinki were on-demand garbage collection (using sensors) for household waste and in parks, and garbage sorting (simplifying sorting, increasing information awareness). Representatives of the authorities and

[5]MyData is a model for personal data use. It refers to, on the one hand, a human-centric model for the management and utilization of personal data, which seeks to endow people with self-determination regarding data about themselves and, on the other hand, to a growing movement working towards the realization of such a model in digital societies globally. Website: https://mydata.org/

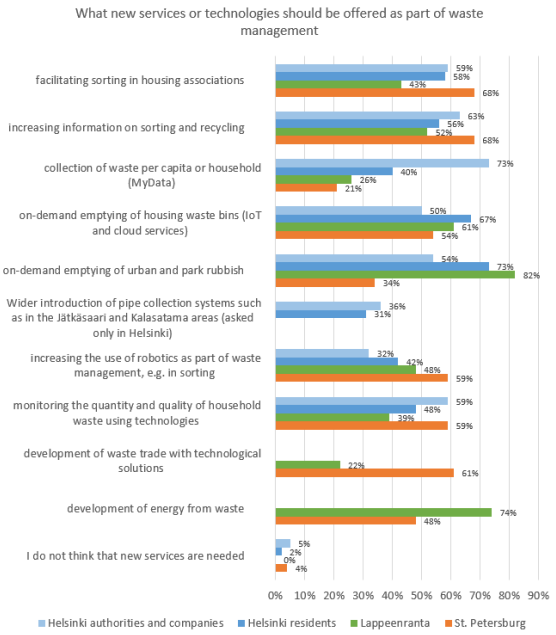

Figure 6: What new services or technologies should be offered as part of waste management

companies in Helsinki gave approximately the same answers as residents. The main difference is that the most popular answer of civic authorities and WM companies was "collection of waste per capita or household (MyData)". This is because, representatives of authorities and companies are much more familiar with this technology than residents. Also, representatives of authorities and companies, to a lesser extent than residents, consider on-demand emptying of waste containers necessary. We associate this with seeing the big picture and having a better understanding of logistics problems. In Lappeenranta, the most popular answer is also garbage disposal on demand (however, a smaller percentage of respondents are sure of the need to use sensors), people are also interested in improving waste separation and the development of energy from waste. In St. Petersburg, the respondents voted with approximately the same activity for sorting garbage (simplifying sorting, increasing information awareness), development of waste trade with technological solutions, and the introduction of almost all proposed technologies, except for MyData.

5 DISCUSSION

5.1 Common findings of all cities. RQ 1: What is the current status, city context, what are the main challenges and needs of WM in the studied northern cities from the point of view of service consumers (i.e., eco-aware residents) and service providers (i.e., authorities and companies)?

Main challenges that are relevant for all cities are in areas of waste sorting and logistics. **Waste sorting** faces several challenges. First, respondents mention that **containers for all the different types of waste** are not available in all households and parts of the city. There is also **no possibility of sorting some types of waste**. City residents and authorities in all three cities considered it necessary to sort more types of waste (for example, fabric in Finland and bio-waste in Russia). In all three cities, it is not possible to **sort waste in parks**, which the majority of respondents feel is needed. The last challenge is in the area of the **reuse and recycling of goods**. In logistics, the main challenge is in the area of **emissions and air quality**.

We also list some additional problems and needs that are less common but typical for cities with a specific context. Respondents reported these issues both in answers to closed-ended questions and in additional comments. Based on the respondents' comments, we hypothesized which context parameters had an impact on the listed problems and needs. Table 2 lists the identified problems by category, and a list of context parameters for each problem is provided.

In the sphere of **waste sorting**, we listed 4 problems and needs. We concluded that typically for large cities without widespread multiple waste type sorting but with good environmental awareness, there are needs for: 1) improved development and implementation of waste sorting, 2) more accessible information about the nearest waste collection points, and 3) better information about the correct sorting of various types of garbage. Problems with sorting multiple types of garbage at home are typical for large cities with sorting of multiple waste types and good environmental awareness (due to the high cost of housing and small kitchen space).

In the area of **logistics** in large or medium-sized cities, respondents indicated problems with traffic noise. Another challenge is associated with the frequency of garbage collection. If at least one type of waste is collected almost every day (Finland), there are problems such as empty runs, and traffic problems created by garbage trucks. If waste is collected once a week or less, as in St. Petersburg, residents complain about overflowing trash containers.

When considering garbage collection in **public places**, residents of large or medium-sized cities complain about overflowing trash cans and an insufficient number of trash cans. In cities with a good ecological situation and good environmental awareness, people complain about birds that spread trash.

5.2 RQ 2: How could IoT or other technical solutions be used to improve WM in a city context?

In this section we suggest possible solutions to the problems listed in section 5.4. The solutions we offer are based technical solutions described by representatives of WM companies in Helsinki and analysis of the literature on the research topic [1], taking into account service consumers' suggestions..

We divided the **problems of waste sorting** into problems associated with a lack of awareness among citizens and problems associated with a lack of infrastructure. Such problems as *sorting multiple types of garbage at home* and *a lack of information about correct sorting of various types of garbage* could be solved by implementing a decision support system (DSS) and providing guidelines in the form of a QR-code [21] at waste collection points and a web

Table 2: Correlation between the context of the city and existing problems and needs

			City context				
			City size	Widespread multiple waste type sorting	Citizens' environmental awareness	Garbage collection frequency	Ecological situation
Problems and needs	Waste sorting	Development and implementation of waste sorting	large	no	high enough		
		Need for information about nearest separate waste collection points	large	no	high enough		
		Need for information about correct sorting of various types of garbage	large	no	high enough		
		Problems with sorting multiple types of garbage at home	large or medium-sized	yes	high		
	Logistics	Traffic noise	large or medium-sized				
		Empty runs				(almost) every day	
		Garbage trucks create traffic problems				(almost) every day	
		Static emptying intervals (sometimes too rare, sometimes too often)				(almost) every day	
		Overflowing trash cans			once a week or less		
	Public places	Not enough trash cans	large or medium-sized				
		Overflowing trash cans	large or medium-sized				
		Birds carry trash			high		good

or mobile app, as well as a poster with a table of different types of garbage and graphics. Such problems as *no information about the nearest separate waste collection points* and *not enough waste containers for some types of garbage* could be solved using a «city dashboard»[22], [23]– an online map, that shows the nearest waste collection points for various types of waste. Problems such as *no possibility of sorting some types of garbage, no reuse and recycling of goods, no waste sorting in parks, a need for development and implementation of waste sorting*, and *not enough waste containers for some types of garbage* could be solved by development and implementation of waste sorting infrastructure.

Logistic problems can be divided into two groups: those related to harm to the environment and those involving inefficiency of the logistics system. As indicated earlier, *logistical problems* can be solved by changes to routes and schedule optimization [24], [25], [26], [27]. The scheduling system can be based on real-time [24], [26] and historical data [27], [25], analyses of data from sensors on garbage bins (fill-level [24], [26], weight [24], gas sensors [26] for bio-waste), data from sensors on garbage trucks (scales, CAN-bus data), and GPS sensors on garbage trucks. Another option may be on-demand emptying. *Problems of empty runs and insufficient waste collection frequency* can be solved by waste compressing (CitySolar Smart bin, 01.02.2023). *Traffic problems* can be solved by changing collection schedules, i.e., collecting waste at night and early in the morning, not during rush hours.

To solve ***problems related to the cleanliness of public places*** such as *not enough trash cans* and *overflowing trash cans*, IoT technologies (fill level sensors), enhanced waste collection routes and schedule optimization can be used. Another option is to install trash cans based on analyses of the most contaminated areas or based on citizens' complaints and feedback service data. To solve the problem with birds that spread trash, we recommend using IoT

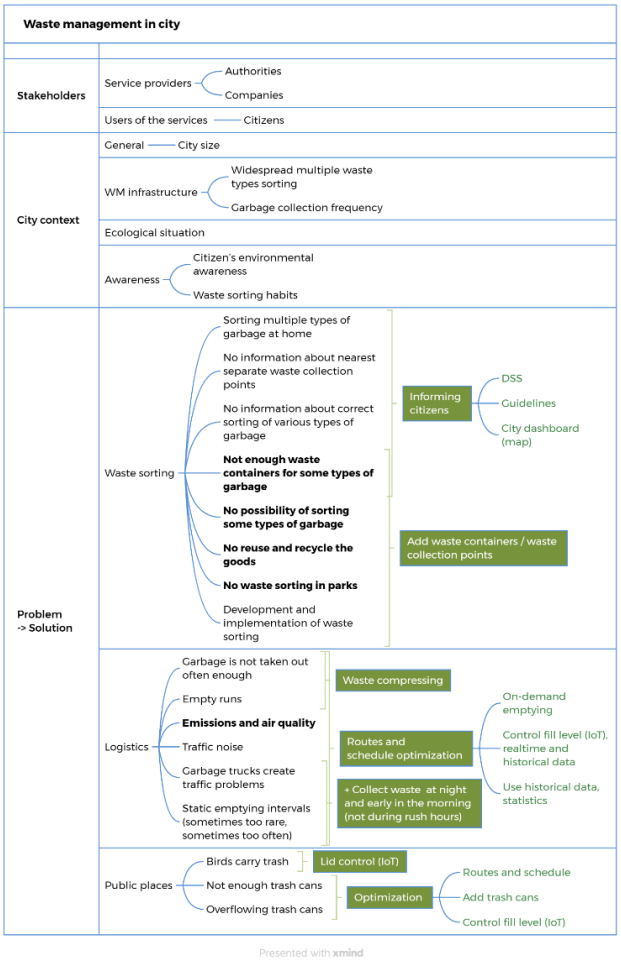

Figure 7: WM city context, problems and solutions model

technologies (motion sensor + lid control actuator) or just to equip trash cans with a lid and a pedal-operated opening mechanism.

As a summary, Figure 7 presents a general model that includes WM system stakeholders, the city context, problems, and solutions. The main challenges that are relevant for all cities are highlighted in bold, and suggested solutions are marked in green.

6 CONCLUSIONS

In this study, we collected and analyzed information from WM stakeholders about the current status, main challenges and needs of WM in the modern city. We focused on 4 topics: household waste sorting and urban waste management, WM logistics, WM in public places (i.e., parks and recreational areas), and new technologies in waste management. We compared different sized northern cities located in different countries. The studied cities also differ in the approach used for waste management, the use of new technologies, available infrastructure as well as the environmental awareness of the population. This allowed us to study waste management in different contexts, results of these approaches and the attitude of the population to the existing problems.

As a result, we found the common problems in the field of waste management for the different sized northern cities. It was found that common problem areas are sorting of multiple waste types, logistics, and maintenance of cleanliness of public spaces. Waste sorting challenges include: 1) availability of containers for all types of waste in all households and parts of the city; 2) possibility of sorting more types of waste; 3) reuse and recycling of goods. In logistics, the main challenge is in the area of emissions and air quality. We found some additional problems and needs that are less common but typical for cities with a specific context and suggest the causes of their occurrence. We also write a short description of each of the studied city context, which include city context parameters, problems and needs.

Based on expert's knowledge and the scientific literature on the topic [1] we proposed modern technological solutions to the identified problems in the form of general guidelines. These guidelines can be used by city authorities and other stakeholders engaged in WM activities.

Future work could valuably expand the set of contextual parameters to provide a more comprehensive overview of the relationship between contextual factors and WM performance. Additionally, hackathons could be used to generate possible solutions to some of the identified problems. Further case studies involving WM companies and interviews with experts in the field may be able to provide additional useful information. Based on the collected materials, a decision support framework will be developed to aid city authorities and citizens find possible solutions to problems and needs in city waste management, taking into account city context.

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APPENDIX

To see the table with the summary of key survey-based works related to WM, please follow the link https://doi.org/10.5281/zenodo.7848939