SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 182

WASTE MANAGEMENT IN SMARTPHONE APPLICATIONS AS ELEMENT OF SMART CITY DEVELOPMENT

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Purpose: The purpose of this publication is to present the usage of smartphone application in Smart Cities in waste management.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The integration of smartphone apps in smart city waste management promises enhanced urban sustainability, efficiency, and citizen engagement. These apps, detailed in Tables 1 and 2, offer real-time monitoring, data-driven decision-making, and environmental benefits. Yet, challenges like the digital divide and data privacy, discussed in Table 3, must be overcome. A comprehensive approach, focusing on accessibility, data security, and sustainability, is essential. Smartphone apps are a critical step toward creating cleaner, healthier, and more sustainable smart cities.

Keywords: Smart City, waste management, smartphone applications, smart mobility.

Category of the paper: literature review.

1. Introduction

In the 21st century, the concept of a "smart city" has gained tremendous momentum, driven by the need for more efficient and sustainable urban environments. One key aspect of smart city development is waste management, a critical component of maintaining cleanliness, health, and sustainability in urban areas. Smartphone applications have emerged as powerful tools to enhance waste management practices, contributing significantly to the realization of smart cities. The integration of smartphone applications into waste management is a tangible and effective means of advancing smart city development. These apps not only enhance operational efficiency but also foster a sense of environmental responsibility among citizens. As cities continue to grow and evolve, waste management through smartphone applications will remain

a fundamental element in the pursuit of cleaner, healthier, and more sustainable urban environments.

The purpose of this publication is to present the usage of smartphone application in Smart Cities in the case of waste management.

2. The usage of smartphone applications in waste management

Smartphone applications play an integral role in the evolution of waste management in urban areas. These applications enable real-time monitoring of waste collection, transportation, and disposal. Sensors embedded in waste bins can transmit data to these apps, allowing waste management authorities to optimize routes, schedules, and resources. As a result, collection trucks can be dispatched more efficiently, reducing fuel consumption and traffic congestion (Wolniak, Sułkowski, 2015, 2016; Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021, 2022).

Smartphone apps engage citizens in the waste management process. Users can report issues such as overflowing bins, illegal dumping, or missed collections through these apps. Such citizen participation fosters a sense of community ownership and responsibility for waste management, which, in turn, leads to cleaner and more sustainable cities. Many applications provide information about waste sorting and recycling, guiding users on how to properly dispose of different types of waste. This educational aspect is vital for reducing contamination in recycling streams and promoting eco-friendly practices (Rachmawati et al., 2021; Dutta et al., 2021; Ivanyi, Biro-Szigeti, 2019).

In some smart cities, waste collection services are billed based on usage. Smartphone apps allow users to make payments conveniently, check their billing history, and receive digital receipts. This not only streamlines the payment process but also reduces the need for physical paperwork. Smartphone applications often include features like news feeds and updates related to waste management and environmental issues. This helps in raising awareness among the community about the importance of responsible waste disposal and encourages eco-conscious behaviors.

By accumulating and analyzing data from these apps, city authorities can gain valuable insights into waste generation patterns, peak disposal times, and areas with recurring waste management issues. Such data-driven decision-making leads to more effective waste management strategies and resource allocation. In smart cities, IoT devices and sensors are increasingly used to monitor waste bins' fill levels, allowing for timely collection. Smartphone applications can integrate seamlessly with these technologies, enabling a more automated and responsive waste management system (Rahman, Dura, 2022).

By optimizing waste collection routes and reducing fuel consumption, these apps contribute to a reduction in greenhouse gas emissions. Furthermore, better waste sorting and recycling practices promote sustainability and environmental conservation (Herdiansayah, 2023; Rose et al., 2021).

Table 1 contains descriptions of how smartphone applications are used in in waste management.

Waste management apps often integrate with IoT sensors placed in waste bins and containers. These sensors monitor the fill levels of the bins and transmit data in real time to the application. This enables waste management authorities to optimize collection routes and schedules, ensuring that collection trucks are dispatched only when necessary, which minimizes fuel consumption and traffic congestion. Smartphone apps use the data collected from real-time monitoring to create efficient collection routes and schedules. This ensures that waste collection trucks take the most direct and time-efficient paths, reducing operational costs and environmental impact.

Citizens can report issues related to waste management through these applications. Whether it's reporting overflowing bins, illegal dumping, or missed collections, user-generated feedback helps authorities respond to problems more quickly and efficiently. Many waste management apps provide guidance on waste sorting and recycling. They educate users on how to properly dispose of various types of waste, helping to reduce contamination in recycling streams and encouraging eco-friendly practices.

In some smart cities, waste collection services are billed based on usage. Waste management apps allow users to make payments conveniently through their smartphones, view their billing history, and receive digital receipts, eliminating the need for physical paperwork and streamlining the payment process (Jonek-Kowalska, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021; Orzeł, Wolniak, 2021, 2022; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021). Waste management apps often include features like news feeds and updates related to waste management and environmental issues. These features help raise awareness among the community about responsible waste disposal and encourage environmentally conscious behaviors (Chmielarz et al., 2021).

Smartphone applications collect and analyze data on waste generation patterns, fill levels, and recurring issues (Rose et al., 2021). By harnessing this data, waste management authorities can make data-driven decisions to improve operational efficiency, reduce costs, and allocate resources more effectively. By optimizing waste collection routes and schedules, these apps lead to a reduction in fuel consumption and greenhouse gas emissions. Additionally, promoting responsible waste disposal and recycling practices through these apps contributes to environmental sustainability (Simonofski et al., 2023; Chmielarz et al., 2021).

Many smart cities use IoT devices and sensors to monitor waste containers. Smartphone applications can integrate seamlessly with these technologies to create a more automated and responsive waste management system. Some waste management apps include educational resources and campaigns that promote sustainable waste disposal practices, increasing public awareness about the environmental impact of waste (Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023).

Smartphone applications have become integral to waste management in smart cities by improving operational efficiency, increasing user engagement, and promoting environmentally sustainable practices. By harnessing real-time data, citizen participation, and advanced technologies like IoT, these applications play a crucial role in transforming waste management into a smarter, more eco-friendly, and efficient process within the context of smart city development.

Table 1.

How smartphone applications are used in waste management

Aspect of Waste Management	Application in Smart City Development
Real-Time Monitoring	Integration with IoT sensors for real-time monitoring of fill levels in waste bins, enabling optimized collection routes and schedules.
Efficient Routing and Scheduling	Utilizing real-time data to create efficient waste collection routes and schedules, reducing operational costs and environmental impact.
User Reporting and Feedback	Allowing citizens to report issues like overflowing bins, illegal dumping, and missed collections for quicker problem resolution.
Waste Sorting Guidance	Educating users on proper waste sorting and recycling through the app to reduce contamination in recycling streams.
Payment and Billing	Enabling users to make payments for waste collection services conveniently, view billing history, and receive digital receipts.
Community Engagement	Engaging citizens through news feeds and updates on waste management and environmental issues to raise awareness and promote eco-friendly behaviors.
Data Analytics	Collecting and analyzing data on waste generation patterns and recurring issues to make data-driven decisions for operational improvements.
Environmental Impact Reduction	Optimizing waste collection to reduce fuel consumption and greenhouse gas emissions, contributing to sustainability.
Integration with IoT and Sensors	Seamless integration with IoT devices and sensors to create an automated and responsive waste management system.

Public Awareness Campaigns	Including educational resources and campaigns within the app to promote sustainable waste disposal practices and increase public awareness.
Collection Point Information	Providing information on the locations of waste collection points and nearby recycling centers, improving accessibility.
User Notifications	Sending reminders and notifications to users about upcoming collection schedules and recycling events.
Waste Reduction Strategies	Offering tips and strategies to help users reduce waste generation and make eco-friendly choices.
Digital Waste Bins	Using digital bins that interact with the app, providing fill-level updates and location details.
Regulatory Compliance	Assisting waste management authorities in ensuring regulatory compliance and monitoring waste-related permits.
Fleet Management	Monitoring and managing the waste collection fleet, optimizing vehicle maintenance and operational efficiency.
Emergency Response	Facilitating quick response during emergencies, such as hazardous waste spills or natural disasters.
Data Security and Privacy	Ensuring the security and privacy of user data and adherence to data protection regulations.
Multilingual Support	Providing support for multiple languages to accommodate diverse user populations in smart cities.
Integration with Payment Systems	Integrating with payment gateways and systems to manage waste service fees securely.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani & Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera & Boutueil, 2018).

Table 2 highlighting the advantages of using smartphone applications in waste management within smart cities. The integration of smartphone applications into waste management systems in smart cities results in a range of benefits, from improved operational efficiency to increased citizen engagement and environmental sustainability.

Table 2.

Advantages of using smartphone applications in waste management

Advantages	Description
Real-Time Monitoring	Allows for immediate, data-driven decision-making and optimization of waste collection and disposal processes.
Enhanced Efficiency	Improves operational efficiency by optimizing collection routes, reducing fuel consumption, and decreasing operational costs.
User Engagement and Awareness	Encourages citizen participation in waste management, fosters community responsibility, and raises awareness about environmental issues.
Waste Sorting and Recycling Guidance	Educates users about proper waste sorting and recycling, reducing contamination and promoting eco-friendly practices.
Streamlined Payment and Billing	Simplifies waste service payments, reduces paperwork, and enhances transparency for users.
Data-Driven Decision-Making	Provides valuable insights into waste generation patterns and recurring issues, enabling data-driven decisions for operational improvements.
Environmental Impact Reduction	Contributes to environmental sustainability by optimizing waste management, reducing greenhouse gas emissions, and promoting responsible waste disposal.
Integration with IoT and Sensors	Enhances efficiency by integrating seamlessly with IoT devices and sensors for real-time monitoring.
Public Awareness Campaigns	Raises public awareness about the importance of sustainable waste disposal and the environmental impact of waste.
Accessibility and Inclusivity	Provides information and services in multiple languages, ensuring accessibility for diverse populations in smart cities.
Emergency Response Capabilities	Facilitates quick response during waste-related emergencies, ensuring a safer and more efficient crisis management process.
Regulatory Compliance and Reporting	Helps authorities ensure regulatory compliance, monitor permits, and generate reports on waste management activities.
Data Security and Privacy	Ensures the security and privacy of user data, promoting trust and compliance with data protection regulations.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani & Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera & Boutueil, 2018).

Table 3 highlighting some of the common problems and challenges associated with the usage of smartphone applications in waste management within smart cities. Addressing these problems requires careful planning, investment, user education, and consideration of inclusivity to ensure that waste management apps are effective and accessible to all residents in a smart city.

Table 3.

Problems of using smartphone applications in waste management within smart cities

Problems	Description
Digital Divide	Not all citizens have access to smartphones or reliable internet connections, leading to potential exclusion from waste management services.
Data Privacy and Security	Handling personal data through apps raises concerns about data security, privacy breaches, and misuse of user information.
Technological Barriers	Some users may struggle to use waste management apps due to limited technological literacy or accessibility issues.
Maintenance and Updates	Frequent updates and maintenance of the application are necessary, which can lead to disruption and compatibility issues.
Costs and Funding	Developing, maintaining, and supporting waste management apps can be expensive and may strain municipal budgets.
Limited Coverage	The availability and coverage of waste management apps may not extend to all areas of a city, leaving some regions underserved.
User Reliability	Relying on user-generated data and reports may result in inaccuracies and unreliable information.
Digital Divide Among Waste Bins	Equipping waste bins with IoT sensors is costly and might not be practical in all areas, leading to disparities in monitoring.
Technological Infrastructure	In areas with limited technological infrastructure, such as poor network connectivity, apps may not function optimally.
Resistance to Change	Users or waste management authorities may resist adopting new technologies, hindering the application's success.
Environmental Impact of Smartphone Use	The production and disposal of smartphones and their impact on the environment may be at odds with sustainability goals.
Compatibility and Interoperability Issues	Integrating waste management apps with existing systems, including those from different vendors, can pose challenges.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani & Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera & Boutueil, 2018).

Using smartphone applications in waste management within smart cities offers numerous advantages, but it also comes with its fair share of challenges and problems. Not everyone in a city has access to smartphones or a reliable internet connection. This digital divide can result in exclusion, with some residents unable to take advantage of the services provided through waste management apps (Dutta et al, 2019).

Handling personal data, including billing information and location data, through these apps raises concerns about data security and privacy breaches. It's crucial to ensure robust security measures to protect user information. Some users may struggle to use waste management apps due to limited technological literacy or accessibility issues, especially among older or less tech-savvy demographics (Kalasova et al., 2021).

Smartphone applications require regular updates and maintenance to ensure their functionality and security. These updates can sometimes lead to temporary disruptions, compatibility issues, or usability problems for users. Developing, maintaining, and supporting waste management apps can be expensive, potentially straining municipal budgets. Funding challenges may limit the scope and quality of these applications.

The availability and coverage of waste management apps may not extend to all areas of a city. Some regions may be underserved, leaving residents without access to the benefits of these apps. Relying on user-generated data and reports can lead to inaccuracies and unreliable information, affecting the overall effectiveness of waste management operations. Equipping waste bins with IoT sensors can be costly and may not be practical in all areas, leading to disparities in monitoring and data collection (Boichuk, 2020).

In areas with limited technological infrastructure, such as poor network connectivity or outdated hardware, waste management apps may not function optimally or may not be accessible to all residents. Users and waste management authorities may resist adopting new technologies due to familiarity with existing processes or concerns about the learning curve, hindering the application's success (Benevolo et al., 2016; Kalasova et al., 2021).

The production, use, and disposal of smartphones themselves can have a significant environmental impact, which may be at odds with sustainability goals of smart cities. Integrating waste management apps with existing systems, especially those from different vendors, can pose technical challenges and hinder smooth interoperability (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021).

To harness the full potential of smartphone applications in waste management within smart cities, it is essential to consider these problems and work toward solutions that ensure inclusivity, data security, and usability while minimizing the negative environmental and social

impacts. This can involve comprehensive user education, infrastructure development, and effective policies and regulations.

3. Conclusion

The integration of smartphone applications into waste management systems within smart cities presents a promising avenue for enhancing urban sustainability, operational efficiency, and citizen engagement. These applications, as detailed in Table 1, offer a multifaceted approach to waste management, encompassing real-time monitoring, user engagement, data-driven decision-making, and environmental impact reduction. The advantages, as outlined in Table 2, are evident in the form of improved efficiency, increased environmental awareness, and streamlined processes, contributing to more sustainable urban environments.

However, the adoption of these applications is not without its challenges, as highlighted in Table 3. The digital divide, data privacy concerns, and technological barriers can potentially hinder accessibility and effectiveness. Maintenance costs, funding constraints, and resistance to change also present significant obstacles that need to be addressed. Moreover, the environmental impact of smartphone production and disposal raises important questions about the alignment of these technologies with sustainability goals.

To overcome these challenges and fully realize the potential of smartphone applications in smart city waste management, a comprehensive approach is necessary. This approach should encompass equitable access, robust data security measures, technology literacy programs, and infrastructure development. It should also address issues related to funding, resistance to change, and sustainability considerations.

In the 21st century, the vision of smart cities is intrinsically linked to innovation and sustainability. Smartphone applications for waste management represent a significant step towards achieving these goals. With careful planning, investment, and a commitment to inclusivity, these applications can play a pivotal role in shaping cleaner, healthier, and more sustainable urban environments for generations to come.

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