

# Barriers to Implementing Industry 4.0 Technologies in Solid Waste Management: Case of the City of Cape Town Metropolitan Municipality

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## Abstract

This qualitative research investigates the primary barriers to implementing Industry 4.0 technologies in the solid waste management system of the City of Cape Town Metropolitan Municipality, South Africa. Data were collected through interviews with 12 participants from the City of Cape Town metropolitan municipality. Purposive sampling was used to obtain the participants. Thematic data analysis was used to analyze the data. The study identifies six interconnected barriers, which were technological unpreparedness, financial and resource constraints, shortage of skilled personnel, organizational and institutional challenges, significant gaps in stakeholder engagement, and environmental and contextual factors, especially in informal settlements. To address these multifaceted barriers, a comprehensive policy approach is recommended, combining infrastructure investment, capacity building, institutional reform, inclusive stakeholder participation, and context-sensitive urban planning. Such integrated efforts are essential for Cape Town to realize the transformative potential of Industry 4.0 and develop a more efficient, equitable, and sustainable solid waste management system.

## Keywords

Barriers, Industry 4.0 Technologies, Sustainable Development Goals, Solid Waste Management, South Africa

## 1. Introduction

The swift development of digital technology, referred to as Industry 4.0 (I4.0), has

transformed many industries by making smarter, data-driven, and more effective systems possible [1]. Traditional waste management systems could be transformed into intelligent, sustainable, and responsive networks by Industry 4.0, which is defined by advancements like the Internet of Things (IoT), artificial intelligence (AI), big data analytics, robotics, and cloud computing [2]. In the context of solid waste management (SWM), these technologies can help with predictive infrastructure maintenance, real-time trash creation monitoring, collection route optimization, and recycling efficiency. Notwithstanding the evident benefits, Industry 4.0 acceptance and use in SWM are still limited, especially in emerging urban settings.

An estimated 12.7 million tonnes of trash are produced domestically in South Africa each year [3]. However, the main challenge is that many South African metropolitan municipalities, such as the City of Cape Town metropolitan, fail to effectively manage solid waste due to diverse barriers. The City of Cape Town metropolitan has a population of over 3 million, and a lot of waste is produced by such a population [4]. The City of Cape Town supports the above assertion and goes on to mention that in 2024, the City of Cape Town manages approximately 2.1 million tonnes of waste annually across residential, commercial, and other waste streams. Such high volumes of waste require effective methods of disposal, especially those embedded in industry 4.0 technologies [5].

Mukweho, Radzuma, & Roos used qualitative research to explore the barriers to effective solid waste management in South African municipalities [6]. The study's findings emphasized a number of significant obstacles, such as inadequate community education, political meddling, corruption, poor budgeting, inadequate infrastructure upkeep, a lack of competent workers, and a lack of monitoring [6]. The study focused on Makadho municipality only. What remains unknown are the key barriers to the implementation of Industry 4.0 technologies in the management of solid waste in the City of Cape Town metropolitan municipality.

Korstanje, Janusz, Van Rompaey, and Roos used content analysis in examining the barriers to municipal solid waste management policy implementation in Kwa-Zulu Natal province, South Africa [7]. The study found that there was a discernible difference in how waste management policies were implemented at the local level in the chosen case study areas, uMhlabuyalingana and Jozini municipalities [7]. Although this research unearthed the key challenges that affect SWM, the study only covered Kwa-Zulu Natal province and nothing is known for the City of Cape Town Metropolitan Municipality.

Siwawa used interviews to examine the effect of the ICT-enabled reclaimer system on the informal waste recycling system in Cape Town, South Africa [8]. Results from the study indicated that the conventional unofficial recycling system has been revolutionised by ICT-enabled trash reclaimer systems [8]. Waste reclaimers were also shown to be important stakeholders, data producers, and co-designers of ICT-enabled waste reclaimer systems. The research by Siwawa is silent on the barriers that impact effective SWM in the City of Cape Town Metro-

politan Municipality [8].

Atofarati, Adogbeji, and Enweremadu assessed the efficiency of smart waste management solutions in urban settings and identified barriers to implementing Centralized Smart Waste Management (CSWM) in African contexts [9]. The research was based on a scoping review methodology, and findings indicated that the CSWM framework has economic, environmental, and social advantages, such as improved resource recovery, job creation, and long-term cost savings. However, obstacles to its implementation include high costs, limited infrastructure, and the requirement for stakeholder engagement [10]. Though this research covers African context SWM issues, it is silent on the specific barriers that affect the City of Cape Town metropolitan.

Therefore, although various researchers have researched SWM in Africa and South Africa, no research has been done to focus on the barriers affecting the implementation of 4IR technologies in the City of Cape Town Metropolitan Municipality [6]-[8] [10]. This current research therefore seeks to tackle this issue, and the research question is stated below:

1. What are the key barriers to the implementation of Industry 4.0 technologies in the management of solid waste in the City of Cape Town Metropolitan Municipality, South Africa?

This study is highly relevant from an academic, practical, and policy standpoint. First of all, it fills a significant study void in the body of knowledge on solid waste management in South Africa that other researchers have overlooked [6] [7] [10]. As a result, this study provides a contextualised and localised understanding of the obstacles to I4.0 integration in waste management procedures in one of the biggest cities in South Africa. Secondly, the research adds to the expanding body of information regarding the digitalisation of urban public services in developing nations. It goes into further detail on the growing conversation about smart city development and how digital innovations might improve sustainability, accountability, and efficiency in the provision of municipal services. By detecting and classifying significant obstacles, whether organisational, financial, technological, or policy-related, the study offers development organisations, technology suppliers, and local government officials insightful information.

The study also has practical implications for enhancing service delivery, encouraging sustainable urban development, and coordinating local waste management systems with environmental goals at the national and international levels. For a more robust and equitable implementation of I4.0 technologies in South African cities, the results can direct policy development and strategic planning. The remainder of the document is organised as follows: The theoretical framework falls under section 2. The methodology is presented in section 3. Section 4 contains the results and discussion. The study's conclusion is given in section 5.

## 2. Theoretical Framework

This study uses the TOE framework to support the issue under discussion. One

well-known paradigm for analyzing how technological advances are adopted and implemented inside organizations is the Technology-Organization-Environment (TOE) framework. Since its initial development by Tornatzky and Fleischer, it has been widely used in research pertaining to organizational innovation, smart technology, and digital transformation [11]. Three crucial factors—technological, organizational, and environmental contexts—are identified by the TOE framework as having an impact on technology adoption.

The organization's pertinent external and internal technologies are included in the technical context [12]. This includes new technologies' accessibility, compatibility, intricacy, and alleged advantages. A municipality like Cape Town's readiness to incorporate these technologies into its current waste management infrastructure is captured by this dimension in the context of Industry 4.0, which includes the Internet of Things (IoT), artificial intelligence (AI), robotics, cloud computing, and big data analytics [13].

Internal attributes like size, structure, available resources, leadership commitment, and human capital are the main emphasis of the organizational context. According to Zhang *et al.*, this involves the capabilities of waste management departments, the availability of qualified staff, financial resources, and strategic alignment between the use of technology and municipal objectives [14].

External forces and impacts like public demand, market competition, vendor support, and regulatory rules are all part of the environmental context [15]. National waste legislation, community expectations, political dynamics, and restricted access to specialized technology suppliers are some of the challenges that South African municipalities frequently confront [16]. The TOE framework is in line with this study on the obstacles to integrating Industry 4.0 technology into the solid waste management system in the City of Cape Town Metropolitan Municipality. The study provides comprehensive knowledge of the various obstacles that impede the adoption of intelligent waste management systems by organizing the research around the organizational, technological, and environmental dimensions. The framework offers a theoretical and analytical lens to distinguish between external constraints, like legal barriers or stakeholder resistance, and internal problems, like a lack of infrastructure or capacity. As a result, it guarantees that the conclusions are based on a thoroughly verified model of innovation adoption in addition to assisting in the creation of focused recommendations.

### 3. Methodology

The study was based on qualitative research methods. The focus was on the City of Cape Town Metropolitan officials only. The City of Cape Town metropolitan council and the university's ethical committee granted permission to collect the data. The top, medium, and lower levels of management in the City of Cape Town metropolitan municipality were the study's target demographic. Purposive sampling was employed to choose the individuals required for data collection in order to achieve this goal [17]. Purposive sampling makes it easier to obtain rich, in-

depth, and contextually relevant data by choosing individuals who are skilled or experienced [18]. To elaborate, purposive sampling can save more time and money than random sampling because it focuses on certain people or groups [19].

The sample size in qualitative research cannot be determined using any consistent or standard number criterion [20]. According to Hennink and Kaiser, in order to achieve data saturation in qualitative research, a sample size of 9 - 17 should be used [21]. Twelve participants made up the sample size in this study, which is more than the minimum of nine recommended by Hennink and Kaiser [21]. Purposive sampling was used in order to obtain this sample. Reaching data saturation is the most crucial requirement for data collection, particularly when employing interviews [22]. The researcher ended the interviews after speaking with the twelfth person because no new information was discovered. **Table 1** shows the demographics of the participants.

**Table 1.** Demographics of participants.

Demographics of participants	Demographics of participants			Educational qualifications
	Pseudonym	Positions	Years of experience	
1	MW1	Project Manager	11	Bachelors
2	MW2	Technical Manager	9	Diploma
3	MW3	Administrative officer	25	Honours
4	MW4	Support Assistant	9	Bachelors
5	MW5	Manager of IT services within Urban Waste Management	15	Bachelors
6	MW6	Principal Professional Officer: Organizational Performance Management	25	Masters
7	MW7	Manager	6	Diploma
8	MW8	Senior Supervisor	27	Diploma
9	MW9	Director: Landfills and Transfer Stations.	30	Masters
10	MW10	Civil Engineer	12	Bachelors
11	MW11	Supervisor	7	bachelors
12	MW12	Operational manager	10	Masters

Twelve participants in research examining obstacles to integrating Industry 4.0 technology in solid waste management within the City of Cape Town Metropolitan Municipality are shown in the table with their demographic and professional information. Each participant has a role related to waste management operations, administration, or strategy and is anonymised using pseudonyms (MW1-MW12). The participants have a variety of positions, including technical, management,

and executive roles like director and principal professional officer, as well as support and supervisory duties. Their years of experience show a wide range of institutional knowledge, ranging from 6 years (MW7) to 30 years (MW9). The majority of participants (5), in terms of educational background, have a bachelor's degree, followed by diplomas (3), master's degrees (3), and one honours degree (MW3). This illustrates a workforce with diverse educational backgrounds, which could affect how open they are to embracing new technologies.

To comprehend the institutional, technological, and human resource constraints to implementing Industry 4.0 technologies in solid waste management, it is crucial to have a staff that is both varied and experienced, as the table illustrates. Their knowledge is crucial in determining the strategic gaps and operational difficulties facing the municipality in as far as solid waste management is concerned.

Online interviews were used to gather data for this investigation. Every interview was captured on audio. Data were gathered using a semi-structured interview guide. Interviews were employed because they allowed the researcher to ask insightful questions that enabled the collection of further data on the topic [23]. Thematic data analysis was used to examine the information gathered from the interviews. This method was chosen because it is adaptable and enables a more thorough interpretation of the themes identified by the research, both of which are beneficial for achieving the study's goals [24]. The researcher was able to investigate the participants' underlying meanings, experiences, and perceptions by using thematic analysis to look beyond obvious patterns [25]. This is especially helpful for comprehending intricate, situation-specific problems like institutional, technological, or environmental obstacles to the adoption of Industry 4.0.

The six steps in Braun and Clarke's thematic analysis are applied continuously and iteratively. These procedures were used in this study's data analysis. In order to obtain a thorough grasp of the data, the researcher must first familiarize oneself with it by reading and rereading transcripts. The creation of preliminary codes, which involved methodically locating and labeling significant elements throughout the dataset, came next. In the third phase, related codes were grouped into probable themes in order to search for topics. Themes were examined and improved in the fourth step to make sure they appropriately depicted the data. In order to convey the core of the themes, the fifth step was defining and naming them. After the study was completed, a logical report with supporting data extracts was produced [26]-[27]. A second coder independently examined some of the data to guarantee coding reliability, and any inconsistencies were discussed and worked out together. In order to verify the accuracy and reliability of interpretations, member checking was also carried out by discussing preliminary findings with participants.

## 4. Results and Discussion

This section presents the results and discussion. The table below shows the themes and codes that were extracted.

**Table 2.** Main themes and codes.

Theme	Codes
Technological Readiness Barriers	Lack of ICT infrastructure—Incompatible legacy systems—Low data integration capacity—Limited access to smart devices—oor system interoperability
Financial and Resource Constraints	High cost of Industry 4.0 implementation—Budget limitations in municipal departments—Lack of funding for innovation—Prioritization of basic services over tech upgrades
Skills and Human Capital Gaps	Lack of technical expertise in 4IR technologies—Shortage of trained personnel—Limited staff capacity for tech operations—Resistance due to low digital literacy
Organizational and Institutional Challenges	Lack of strong leadership commitment—Poor municipal interdepartmental coordination—Bureaucratic inertia—Weak change management strategies
Stakeholder engagement	Low public or community awareness of smart waste initiatives—Exclusion of the informal sector (waste reclaimers)—Limited private sector collaboration
Environmental and contextual factors	Informal settlements complicate infrastructure deployment

**Table 2** shows that the main themes that emanated from the research findings were: Technological readiness barriers, financial and resource constraints, skills and human capital gaps, organizational and institutional challenges, stakeholder engagement issues, and environmental and contextual factors. Different codes were also extracted from each code.

Overall, the themes that were used in the study resonate with the Technology-Organization Framework. **Table 3** below is used to illustrate this.

**Table 3.** Main themes and codes.

Technology Organizational Framework Component	Themes Used
Technology	Technological readiness
Organization	Financial and Resource Constraints—Skills and Human Capital Gaps—Organizational and Institutional Challenges
Environment	Stakeholder Engagement—Environmental and Contextual Factors

A useful lens for comprehending the main obstacles to integrating Industry 4.0 technology into solid waste management in the City of Cape Town is the Technology-Organization-Environment (TOE) framework, which was discussed prior. According to this TOE framework, organisational, environmental, and technological settings are the three main factors that affect the adoption of new technologies. The results from themes 1 through 6 closely match these dimensions,

demonstrating the intricacy and interconnectedness of the obstacles faced in this situation. **Table 2** shows that the technological readiness theme falls under the Technology component in the TOE Framework. On the other hand, the following themes: financial and resource constraints, skills and human capital gaps, and organizational and institutional challenges fall under the Organization component of the TOE. Finally, the two themes, which were Stakeholder Engagement and Environmental and Contextual Factors, are linked to the Environment component under the TOE framework.

Each theme will be discussed below, and the extracts of responses from the participants will be presented. The presentation of the participants' responses may not follow any exact chronological order. Apart from that, pseudonyms will be used for each participant (MW1-MW12). This was done to conceal the true identities of the participants who took part in the study as well as to fulfill research ethical standards.

#### **4.1. Theme 1: Technological Readiness Barriers**

##### **Response of participants**

On this theme, the participants pointed out that technological barriers affect the implementation of 4.0 technologies in solid waste management. The following responses were extracted that relate to this theme.

“In our municipality there is a lack of modern ICT infrastructure”—(MW1, interviewed Nov 2024).

“We're still using outdated systems that don't integrate well”—(MW4, interviewed Nov 2024).

“Our municipal systems cannot handle real-time data integration efficiently”—(MW7, interviewed Nov 2024).

“There's limited availability of smart devices for field operations”—(MW12, interviewed Nov 2024).

##### **Implication of responses**

The City of Cape Town Metropolitan Municipality faces major obstacles in terms of technological readiness when using Industry 4.0 technology for solid waste management. Participant responses reinforce this theme, which identifies outdated operating procedures and a lack of fundamental ICT infrastructure as major obstacles in solid waste management.

The lack of contemporary ICT infrastructure, which is essential for enabling intelligent waste management solutions like sensor-based waste collection, real-time tracking, and automated sorting technologies, was frequently brought up by participants. For example, MW1 specifically mentioned a lack of contemporary ICT infrastructure, which is a problem that is consistent with research by Agyemang, Anderson, Patiño, & Tremolieres, who contend that the adoption of Industry 4.0 solutions in African urban municipalities is hampered by a lack of digital infrastructure [28].

Additionally, MW4 and MW7 identified inefficiencies in real-time data integration and obsolete technologies. These restrictions make it more difficult to implement integrated platforms, Internet of Things (IoT) apps, and advanced analytics, all of which are necessary for intelligent waste management. According to Gulyamov, Industry 4.0-enabled urban services rely heavily on real-time data processing, and these technologies cannot be fully utilized by systems that are unable to offer this feature [29].

The lack of infrastructure is further highlighted by MW12's statement regarding the restricted availability of smart gadgets. To operationalize smart trash systems, field workers' mobile devices, GPS-enabled rubbish vehicles, and smart bins are essential [30]. Even well-designed digital frameworks cannot be implemented successfully on the ground without these. Each of the 12 participants acknowledged the municipality's lack of readiness for the technology revolution in waste management by expressing or agreeing with these worries. These findings confirm that being technologically ready entails extensive systemic and infrastructure improvements rather than just obtaining new tools.

The findings indicate that one of the biggest obstacles to implementing Industry 4.0 in Cape Town's solid waste management system is still technological preparedness. To close this gap and meet the objectives of the digital transformation, smart device adoption, system modernization, and strategic investment in ICT infrastructure are needed.

## 4.2. Theme 2: Financial and Resource Constraints

### Response of participants

"The cost of implementing Industry 4.0 is too high"—(MW1, interviewed Nov 2024).

"The main barrier is that our department faces serious budget limitations every financial year"—(MW2, interviewed Nov 2024).

"There's no dedicated funding to support innovation projects which fall under 4.0 technologies"—(MW7, interviewed Nov 2024).

"We can't afford new technology with current financial resources"—(MW8, interviewed Nov 2024).

"Most of our budget goes to basic service delivery, so funding to obtain modern 4.0 technologies is limited"—(MW9, interviewed Nov 2024).

"Advanced technologies are too expensive for local government budgets"—(MW10, interviewed Nov 2024).

### Implication of responses

One of the main obstacles to the implementation of Industry 4.0 technologies in the solid waste management system of the City of Cape Town is the lack of funding and resources. The municipal waste department's exorbitant expenses and ongoing underfunding were frequently brought up by participants, underscoring a structural problem with public sector budgeting for technological innovation.

One of the main challenges highlighted by MW1, MW8, and MW10 is the high

capital cost of Industry 4.0 technology. This is in line with research by Bag *et al.* (2021), who contend that, particularly in poor nations, the cost of deploying smart technologies like cloud infrastructure, AI-based garbage sorting, and IoT-enabled bins often surpasses local governments' financial means.

MW2 and MW9 reaffirmed this worry by highlighting ongoing financial constraints, with the majority of funds going towards providing essential services. This is indicative of a larger problem in public administration, as immediate needs frequently take precedence over long-term innovation plans [31]. This makes it challenging for cities like Cape Town to prioritize investments in transformational technology when the supply of essential services is being strained.

Additionally, MW7 pointed out that there was no specific funding for innovation, indicating that there was neither strategic earmarking nor organized financial planning for smart city projects. This is consistent with the findings of Javaid, Haleem, Singh, Suman, & Gonzalez, who stress that the adoption of Industry 4.0 technologies would remain dispersed and unsustainable in the absence of institutional frameworks to finance and maintain innovation projects [32].

Financial restrictions are common and severe, as evidenced by the fact that all twelve participants agreed with these limitations. These restrictions not only make it more difficult to acquire technology, but they also have an impact on maintenance, system integration, and training, all of which are crucial for sustained effective solid waste management.

In conclusion, Cape Town's solid waste management cannot fully adopt Industry 4.0 due to resource and financial constraints. In order to address this, specific financial mechanisms, public-private partnerships, and national assistance are needed to close the gap in municipal resources and promote sustainable technological innovation.

### **4.3. Theme 3: Skills and Human Capital Gaps**

#### **Response of participants**

"We don't have the technical skills for smart systems"—(MW2, interviewed Nov 2024).

"There's a shortage of trained personnel in our unit"—(MW3, interviewed Nov 2024).

"The challenge is that most staff lack experience with 4IR technologies"—(MW4, interviewed Nov 2024).

"Technical training on 4IR technologies for use in solid waste has not been prioritised in our department"—(MW5, interviewed Nov 2024).

"We need more qualified people to manage smart systems, robots, internet of things"—(MW10, interviewed Nov 2024).

"Staff capacity is limited for operating new technologies"—(MW12, interviewed Nov 2024).

#### **Implication of responses**

One major obstacle to the adoption of Industry 4.0 technology in the solid waste

management sector of the City of Cape Town is the dearth of technical expertise and human resources. Participants repeatedly mentioned a lack of skilled workers and a lack of ability to use or oversee smart technologies, indicating serious structural flaws in workforce preparedness.

The lack of technical knowledge and experience with Fourth Industrial Revolution (4IR) technologies, including automation, data analytics, and the Internet of Things (IoT), was specifically mentioned by MW2, MW3, and MW4. This result is consistent with the findings of Jerab, who points out that a workforce that is not equipped to handle technological disruption frequently undermines digital transformation in public services, particularly in developing nations [33].

Furthermore, according to MW5, there appears to be a lack of strategic human resource planning as training on 4IR technologies has not been given priority. This is in line with Ncamphalala & Vyas-Doorgapersad's contention that African municipalities' capacity-building initiatives frequently fall behind technical developments, leading to a lack of alignment between workforce capabilities and innovation objectives [34].

More skilled workers are required to oversee and run smart systems, according to MW10 and MW12. This includes both technical operators and strategic experts capable of managing projects related to digital transformation. The sustainability and scalability of any potential pilot projects are also impacted by the staff capacity constraints.

Every participant either voiced or agreed with these worries, showing that the municipality as a whole widely recognizes this obstacle. Even the most well-funded or technologically advanced projects are likely to fail or function poorly in the absence of trained personnel. Additionally, a lack of technical expertise may result in opposition, ineffective operations, and a greater need for outside consultants, all of which could put additional burden on already tight municipal finances [35].

In conclusion, the effective integration of Industry 4.0 in solid waste management depends on closing the human capital gap. To create a workforce that is prepared for the future, municipalities must make investments in ongoing training, collaborations with academic institutions, and targeted hiring.

#### **4.4. Theme 4: Organizational and Institutional Challenges**

##### **Response of participants**

"I think there's no strong leadership driving digital transformation forward"—(MW2, interviewed Nov 2024).

"We lack committed leadership to support innovation projects"—(MW3, interviewed Nov 2024).

"Departments don't coordinate well on smart waste initiatives"—(MW4, interviewed Nov 2024).

"Poor collaboration between municipality units delays system implementation"—(MW5, interviewed Nov 2024).

"Bureaucracy slows every step of the decision-making process"—(MW6, in-

interviewed Nov 2024).

“It’s difficult to move fast within municipal red tape”—(MW7, interviewed Nov 2024).

### **Implication of responses**

One major obstacle to the effective integration of Industry 4.0 technology in the solid waste management system of the City of Cape Town is the existence of institutional and organizational impediments. Lack of institutional adaptability, interdepartmental collaboration, and leadership, all essential for facilitating technological transformation, was often highlighted in participant replies.

The lack of strong and dedicated leadership, which is essential for establishing strategic direction, allocating resources, and promoting an innovative culture, was a recurrent problem (MW2, MW3). Muktamar, Bachtiar, & Guntoro assert that transformational leadership is crucial for managing digital transformation in public institutions, particularly when disruptive and complicated technologies are at play. Innovation initiatives lack institutional support and momentum in the absence of visionary leadership, and this can have detrimental effects in harnessing 4IR technologies for use in solid waste management.

Participants also mentioned that a problem jeopardizing the integrated planning and implementation of smart waste systems is the dispersed coordination amongst municipal agencies (MW4, MW5). According to Insani, Azwari, & Al Syahrin, a significant barrier to smart city government is siloed bureaucracies, which hinder cross-functional cooperation necessary for data-driven and networked solutions like centralized data dashboards or IoT-based trash tracking [32] [36].

Another significant obstacle was institutional rigidity. MW6 and MW7 explained how excessive red tape and bureaucratic delays impede procurement and decision-making processes. This is in line with research by Enaifoghe & Ndebele, who contend that rigid institutional frameworks in many African towns hinder innovation and risk-taking by making it harder to adjust to rapidly changing technology environments. Every participant acknowledged these challenges, illustrating the widespread organizational inertia. These institutional shortcomings hinder the use, scale, and sustainability of 4IR technologies in solid waste management.

In conclusion, for the waste industry in Cape Town to successfully implement Industry 4.0, organizational change is equally crucial as financial and technological resources. Improving leadership, promoting interdepartmental collaboration, and simplifying bureaucratic processes are the main factors that enable digital innovation for effective solid waste management.

## **4.5. Theme 5: Stakeholder Engagement Issues**

### **Response of participants**

“In my view, the public isn’t aware of smart waste initiatives”—(MW7, interviewed Nov 2024).

“There’s very little community outreach on digital waste systems”—(MW8,

interviewed Nov 2024).

“People don’t understand what smart waste management really means, and it’s tough to implement it”—(MW9, interviewed Nov 2024).

“I think at times the waste pickers are not included in formal planning”—(MW10, interviewed Nov 2024).

“The challenge is that community members don’t participate in waste tech decisions”—(MW11, interviewed Nov 2024).

### **Implication of responses**

One major obstacle to the City of Cape Town’s adoption of Industry 4.0 technology in solid waste management is the difficulty in engaging stakeholders. Participants emphasized the lack of community involvement, low public knowledge, and the exclusion of informal actors as barriers to the practical adoption and social acceptability of smart trash initiatives.

A glaring discrepancy between public awareness and municipal innovation initiatives was noted by MW7, MW8, and MW9. This suggests that the public’s support and involvement in digital waste systems are weakened by their general lack of knowledge. According to Nahhas, public education and awareness are essential for enabling smart city technologies, particularly those that call for behavioral shifts like automated collection systems or sensor-based recycling [37].

Concerns about equity are also raised by MW10’s remark that informal waste pickers are not included in formal planning procedures. In South Africa’s waste value chain, informal players are essential, and disregarding their opinions might lead to resistance and lower system efficacy [38]. To ensure that disadvantaged populations are not displaced by the adoption of 4IR technologies, inclusive planning is required to blend traditional and emergent practices.

MW11 also saw a lack of community involvement in decisions pertaining to technology. This is consistent with research by Vlahos, who contends that localized innovation requires participatory government. Municipalities run the risk of enacting top-down solutions devoid of community ownership or contextual relevance if extensive stakeholder input is not conducted [39].

Every participant directly acknowledged the difficulties in engaging stakeholders. Participatory frameworks that inform, consult, and integrate formal and informal stakeholders in the smart waste transition are critically needed, according to this consensus.

In conclusion, the successful adoption of Industry 4.0 in Cape Town’s garbage industry is hampered by insufficient stakeholder involvement, which is characterized by public ignorance, limited outreach, and the exclusion of important actors. Stronger community-municipality cooperation, inclusive planning procedures, and focused public education campaigns are needed to address this.

## **4.6. Theme 6: Environmental and Contextual Factors**

### **Response of participants**

“Informal settlements make it hard to install smart systems; they are stolen

or vandalised”—(MW1, interviewed Nov 2024).

“It’s difficult to deploy 4IR infrastructure in informal areas”—(MW2, interviewed Nov 2024).

“Unplanned settlements lack structure for smart waste technology integration”—(MW3, interviewed Nov 2024).

“Infrastructure rollout is challenging in dense informal communities”—(MW4, interviewed Nov 2024).

“We struggle to reach informal areas with digital tools and modern technology”—(MW5, interviewed Nov 2024).

### **Implication of responses**

The use of Industry 4.0 technology in solid waste management in the City of Cape Town is severely hampered by environmental and contextual factors, especially the existence of informal settlements. In unplanned and heavily inhabited areas, participants frequently mentioned challenges with infrastructure rollout, system integration, and security issues.

In informal settlements, smart technologies like IoT sensors and smart bins are frequently susceptible to theft or vandalism, as noted by MW1 and MW2. The adoption of high-value technologies is recognized to be complicated by socioeconomic inequality and security concerns in developing urban situations [40]. These flaws discourage investment in solid waste management fields in addition to raising implementation costs.

Informal settlements lack the spatial and physical organization needed to integrate digital infrastructure, according to MW3 and MW4. It is also challenging to implement technologies that depend on structured urban design in many of these places due to their uneven layouts, lack of formal street grids, and erratic availability of electricity or connectivity [41]. As a result, smart technologies made for formal metropolitan settings may not work well in these settings.

Furthermore, MW5 pointed out that using digital tools to reach informal groups is still a challenge. The systematic exclusion of marginalized communities from technological breakthroughs is a reflection of larger problems of infrastructure inequality and digital exclusion [42]. The efficacy and inclusivity of smart waste efforts are compromised in the City of Cape Town metropolitan municipality when these disparities are not addressed.

Contextual realities, such as informality, must be at the heart of planning, according to the five participants who spoke on this issue and the other participants who concurred. Ignoring these problems could lead to remedies that only help more formalized, wealthy areas and reinforce urban inequality. In conclusion, there are major contextual and environmental obstacles to overcome before Industry 4.0 technologies can be successfully incorporated into Cape Town’s waste management system. To promote fair technological inclusion and adapt digital infrastructure for informal settlements, specific, context-sensitive strategies are required.

### **Policy recommendations**

A series of coordinated policy interventions is needed to solve the various ob-

stacles preventing the City of Cape Town from implementing Industry 4.0 technology in solid waste management. First and foremost, the municipality ought to create an investment plan for digital infrastructure that gives priority to the modernization of ICT systems and the gradual, context-sensitive deployment of 4IR technologies in both formal and informal domains. To lessen reliance on limited service delivery budgets, dedicated innovation financing must be created within municipal budgets, perhaps with the help of grants from the federal government or public-private partnerships.

Policies should support targeted skill development in order to close the human capital gap. This includes hiring digital professionals for municipal structures and providing waste management employees with ongoing training on 4IR technologies. This must be supported by lucrative wages and salaries since these are specialized skills.

Additionally, institutional reforms are required, such as the creation of inter-departmental task teams for digital transformation and the bolstering of leadership capabilities to support innovation within municipal units of the City of Cape Town Metropolitan Municipality. The City of Cape Town Metropolitan Municipality should also implement inclusive stakeholder involvement rules that incorporate community discussions, public awareness campaigns, and official acknowledgement of informal waste pickers in planning and decision-making procedures. Programs for digital literacy that improve community preparedness for smart waste initiatives can help support these efforts. Finally, in order to ensure that vulnerable groups do not lose out on the advantages of technology due to spatial inequality, urban planning regulations need to be updated to allow for the organized integration of smart technologies into informal settlements. All of these legislative initiatives ought to be incorporated into a data-driven, inclusive, and spatially and socioeconomically sensitive smart waste management plan for the entire City of Cape Town Metropolitan Municipality.

#### **Suggestions for future studies**

While this study provides valuable insights into the barriers affecting the implementation of Industry 4.0 (4IR) technologies in solid waste management within the City of Cape Town Metropolitan Municipality, future research could build on these findings in several ways. First, a quantitative method that makes use of statistical or economic models might be used to assess the relative impact of each obstacle that has been discovered and to supplement these qualitative findings. Second, case studies that compare other South African municipalities or comparable urban settings in developing nations might be helpful in comparing and generalizing the obstacles and solutions that have been discovered. Regional patterns, common difficulties, and distinctive institutional reactions might be shown in this way. Lastly, further research should explore the role of community perceptions, behavioral change, and the informal waste sector, particularly in informal settlements, to ensure inclusive and socially equitable smart waste management systems.

## 5. Conclusion

The research aimed to identify the key barriers to the implementation of Industry 4.0 technologies in the management of solid waste in the City of Cape Town Metropolitan Municipality, South Africa. The study's conclusions point to six interconnected obstacles that the City of Cape Town's solid waste management system faces when attempting to successfully implement Industry 4.0 technologies. The main issue is technological unpreparedness, as the deployment of real-time, data-driven waste solutions is significantly hampered by antiquated infrastructure and a shortage of smart devices. Financial and resource limitations make this problem even more difficult because smart technology is expensive and innovation funding is scarce, making technological transformation unfeasible for the municipality. The lack of technical expertise and qualified staff is another barrier to advancement, limiting not just the adoption of new systems but also their integration and upkeep. Transformation efforts are severely weakened when human potential is lacking, even with sufficient resources and equipment. This is made worse by organizational and institutional constraints, where bureaucratic inertia, departmental silos, and poor leadership make it difficult to plan and carry out innovation projects in a coordinated manner. Deficits in stakeholder engagement have also resulted in low community involvement and public understanding of SWM. Finally, environmental and contextual limitations pose spatial, infrastructure, and security issues that make the use and implementation of 4IR technologies in SWM difficult, especially in informal settlements. A comprehensive and phased policy strategy that incorporates institutional reform, infrastructure investment, capacity building, inclusive stakeholder engagement, and context-sensitive urban design is needed to overcome these obstacles. The City of Cape Town can only unleash the transformative potential of smart technologies and establish a more effective, fair, and sustainable waste management system by implementing such integrated and inclusive initiatives.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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