Socio-economic Drivers of Smart Waste Management Implementation in the South African Construction Industry

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Abstract: In many developed countries, smart waste management (SWM) is widely used to minimise material waste, improve resource efficiency and support environmental sustainability. However, the construction sector in developing regions continues to exhibit poor waste management practices, resulting in negative impacts on the built environment. Therefore, this study explores the socio-economic drivers of SWM implementation in South Africa's construction sector. To gather relevant insights into these drivers, structured questionnaires were distributed to construction professionals using purposive and snowball sampling. The results show that all 25 socio-economic drivers were statistically significant in the implementation of SWM in the construction industry. The Shapiro-Wilk test was used to assess whether the dataset followed a normal distribution and the results indicated that a non-parametric analysis was required. Consequently, the Kruskal-Wallis H-test was applied, which showed significant differences in the respondents' views regarding the identified drivers. Factor analysis categorised the socio-economic drivers into six categories: financial and resource efficiency, environmental sustainability, policy and regulatory, organisational and managerial, social and human capital, and stakeholder collaboration. The study concludes that the highlighted socio-economic drivers play a critical role in supporting the adoption of SWM within the South African construction industry.

Keywords: Socio-economic drivers, Smart waste management, Construction industry, Waste management, Construction waste

INTRODUCTION

The construction industry is a driver of economic growth and societal development, expanding infrastructure, creating jobs and advancing technology (Alaloul et al., 2021). It supports urbanisation and enhances quality of life by providing essential structures such as housing, transportation networks and public facilities (Ofori, 2015). However, the industry is also among the largest generators of waste and ineffective waste management practices pose serious environmental and economic challenges. Iyiola, Shakantu and Daniel (2024) mentioned that the poor handling and disposal of construction waste led to resource depletion, pollution and increased project costs, while also

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contributing to land degradation and greenhouse gas emissions. Addressing these issues is therefore critical in ensuring that the built environment continues to promote sustainable development without compromising environmental integrity.

South Africa, like many countries, continues to face serious waste management challenges that contribute to environmental degradation, threaten public health and reduce urban quality of life, particularly in vulnerable communities. Adeleke et al. (2021) highlight persistent issues, including illegal dumping, inadequate collection services and improper disposal practices. Similarly, Kubanza and Simatele (2020) argued that South Africa's waste management system remains largely unsustainable. Smart waste management (SWM) is not yet fully integrated, with limited collaboration between public and private sectors, low environmental awareness and weak cleanliness standards. Although several studies have explored enhancing the circular economy through SWM in urban areas, existing waste management approaches remain inefficient and fragmented. These ongoing challenges underscore the need for a holistic, systems-based strategy that fosters stakeholder collaboration and drives effective waste solutions. Consequently, the adoption and implementation of SWM has become essential.

Several scholars define SWM as a technology-driven approach that enhances waste management efficiency and sustainability. Yadav, Soni and Kumar (2023) described it as the use of modern tools to manage and reduce waste more effectively. Zhang et al. (2019) identify key technologies, including Internet of Things (IoT), building information modelling (BIM), big data, cloud computing, cyber-physical systems and artificial intelligence, that enable improved waste monitoring, collection, tracking, sorting and transportation. Rodrigo et al. (2024) added that SWM supports material tracking, recycling, reuse and landfill reduction. From a supply chain perspective, Zhang et al. (2023) highlighted that Industry 4.0 technologies, particularly IoT, automate waste identification and sorting across project stages. Thus, SWM goes beyond waste handling to enhance system-wide efficiency, supporting circular economy principles and sustainable urban development.

Despite the importance of SWM systems, their adoption remains limited in many developing countries (Fatimah et al., 2020; Khan and Ali, 2022; Yadav, Soni and Kumar, 2023). Beyond technological capability, the successful implementation of SWM is deeply influenced by socio-economic factors, including cost efficiency, regulatory enforcement, market competitiveness, organisational readiness, skills development and social expectations, which significantly shape adoption decisions within the construction industry. Implementing SWM in developing countries can be challenging for the following reasons and success requires addressing them. Various researchers have explored digitalisation in construction and its potential benefits. For example, Han, Kalantari and Rajabifard (2021) demonstrated that digital tools, such as BIM and IoT sensors, can enhance waste tracking and resource efficiency; however, this study remains conceptual or limited to pilot implementations in developed contexts, leaving a gap in evidence on how socio-economic conditions influence adoption in developing countries. Chen et al. (2022a) identified digital solutions for construction waste management and emphasised the technical feasibility of smart waste-tracking and sorting. Although valuable, these reviews did not empirically investigate stakeholder perceptions of socio-economic enablers and constraints, particularly within the construction environment.

In this context, drivers represent the forces that both encourage and pressure firms to adopt SWM. They also include the underlying influences, motivations and expected improvements that support the uptake of an effective SWM system. The lack of effort to bring together the different SWM socio-economic drivers makes it challenging to guide their use in the construction sector. This also makes it hard for companies to create a clear, practical plan to implement these practices and achieve their goals. Therefore, this study evaluates the socio-economic drivers of SWM implementation in construction firms in South Africa.

LITERATURE REVIEW

A Summary of Smart Waste Management in the Built Environment

SWM integrates advanced technologies such as IoT, BIM, artificial intelligence and data analytics to optimise construction processes across the project lifecycle. These intelligent systems improve monitoring and operational efficiency while reducing environmental impacts. Prior studies emphasise their transformative role in construction waste management. For instance, IoT devices enable the real-time tracking of waste generation, segregation and disposal, thereby improving resource efficiency and reducing the reliance on landfills (Sharma et al., 2020). BIM supports waste minimisation by identifying potential waste points at the design stage. Similarly, machine learning and deep learning can predict construction waste patterns and recommend optimised handling strategies, supporting circular economy adoption and data-driven decision-making (Iyiola, Shakantu and Daniel, 2024). Despite their potential, these technologies are more widely implemented in developed countries. Developing regions continue to face infrastructure deficits and limited technological access, constraining effective construction waste management. Further research is therefore needed to explore how innovative technologies can be adapted to address waste challenges in rapidly urbanising developing contexts.

Socio-Economic Drivers of Smart Waste Management in the Construction Industry

Socio-economic drivers significantly shape the adoption and performance of SWM in the construction industry. The study of Zhang et al. (2023), which focuses on the operations management perspective of SWM at the corporate level and in supply chains, attributes these major drivers to financial incentives, institutional support, overcoming operational challenges, the availability of digital infrastructure, employment creation and social awareness. This study is largely discussed in terms of individual influences. High upfront costs remain a major barrier to the adoption of smart technologies, including digital tracking and automated sorting systems (Rodrigo et al., 2024). Financial incentives can ease this burden and encourage investment, as firms are more willing to adopt technology when the financial risks are reduced (Zhang et al., 2019). Employment generation is another important driver. Innovative recycling and circular economy initiatives create new jobs and formalise roles within the waste sector (Fatimah et al., 2020; Rafiq et al., 2025). Additionally, social awareness and capacity development influence SWM uptake. Training programmes and awareness campaigns enhance the stakeholders' understanding of smart waste benefits, increasing participation in waste segregation and digital reporting (Khan and Ali, 2022; Yadav, Soni and Kumar, 2023). Table 1 shows some of the socio-economic drivers of SWM retrieved from literature.

Table 1. Socio-economic drivers of SWM

Code	Socio-economic Drivers of SWM	Source
DR1	Availability and investment in digital infrastructure	Zhang et al. (2019); Iyiola and Shakantu (2025)
DR2	Affordable cost of SWM services	Yadav, Soni and Kumar (2023); Rafiq et al. (2025)
DR3	Availability of financial and technical support for implementing SWM	Khan and Ali (2022); Iyiola, Shakantu and Daniel (2024)
DR4	Development of SWM policies and regulations	Yadav, Soni and Kumar (2023); Zhang et al. (2023)
DR5	Reduced SWM operations expenses	Iyiola and Shakantu (2025)
DR6	Stakeholders' collaboration and engagement in SWM initiatives	Zhang et al. (2019; 2023)
DR7	Promotion of recycling and circular economy practices	Sharma et al. (2020)
DR8	Sustainable use of natural resources	Fatimah et al. (2020); Shojaei et al. (2021)

(*Continued on next page*)

Table 1. *Continued*

Code	Socio-economic Drivers of SWM	Source
DR9	Compliance with environmental standards and policies	Rayhan et al. (2025)
DR10	Lower carbon footprint from waste reduction efforts	Yi et al. (2024)
DR11	Leadership and management commitment to innovation	Zhang et al. (2019; 2023); Iyiola and Shakantu (2025)
DR12	Effective planning and coordination of SWM activities on construction sites	Sharma et al. (2020)
DR13	Integration of SWM in construction project planning	Iyiola, Shakantu and Daniel (2024)
DR14	Efficient communication and information flow among project teams	Iyiola, Shakantu and Daniel (2024)
DR15	Promotion of a sustainability and innovation-oriented organisational culture	Fatimah et al. (2020)
DR16	Institutional frameworks for monitoring and evaluation	Iyiola and Shakantu (2025)
DR17	Government incentives and funding support	Zhang et al. (2019); Iyiola, Shakantu and Daniel (2024)
DR18	Efficient use of construction materials and resources	Iyiola and Shakantu (2025)
DR19	Public-private partnerships for policy implementation	Tanveer et al. (2025)
DR20	Compliance with local and international sustainability standards	Rayhan et al. (2025)
DR21	Improved awareness and perception of SWM in construction	Khan and Ali (2022); Yadav, Soni and Kumar (2023)
DR22	Knowledge sharing and continuous improvement strategies among professionals	Zhang et al. (2019); Zhang et al. (2023)
DR23	Workforce training and capacity building for Industry 4.0 skills	Elghaish et al. (2022); Rodrigo et al. (2024)
DR24	Reduction in landfill waste and pollution	Yang et al. (2017); Chen et al. (2022b)
DR25	Availability of employment opportunities through SWM initiatives	Iyiola and Shakantu (2025)

METHODOLOGY

Research Design

This study employed a quantitative research approach, as it enables the collection of numerical data that can be statistically analysed to uncover trends, assess relationships among variables and draw objective, evidence-based conclusions. In addition, the findings from the literature review were essential, as they provided the basis for progressing to the next stage of the research. The target population was comprised of construction professionals, including construction managers, civil engineers, project managers, architects and quantity surveyors.

Sampling Techniques

Purposive and snowball sampling strategies were used to identify and engage participants in the study (Yukalang, Clarke and Ross, 2018; Ratnasabapathy, Alashwal and Perera, 2021). This ensured that the collected data came from well-informed individuals who could provide meaningful insights. Purposive sampling was used to target construction professionals with demonstrable experience in construction activities and waste management practices. Eligibility was determined by the respondents' professional role and their involvement in construction-related projects. Background questions in the survey captured the respondents' job positions and years of industry experience and only responses from individuals with relevant professional experience were retained for the analysis. In addition, snowball sampling was used to reach more qualified participants by asking the initial respondents to recommend other experts or professionals who met the study criteria. This combined approach helps to access a wider network of knowledgeable individuals.

Questionnaire Development

The data were collected using a structured online questionnaire administered via Google Forms to construction professionals in South Africa. The questionnaire included a preliminary section that captured the respondents' demographic and professional information, such as job role and years of industry experience, to ensure that the participants had relevant expertise. Using Google Forms as the primary mode of communication helps to reach a wide range of participants without geographical restrictions. This approach allowed the respondents to complete the questionnaire at their convenience using internet-enabled devices. The questionnaire link was shared to potential participants via online platforms like WhatsApp to ensure accessibility and voluntary participation. The survey included closed-ended questions measured on a five-point Likert scale, with 1 representing "Strongly Disagree" and 5 representing "Strongly Agree". From the survey, 195 valid responses were received.

Data Analysis

The data were analysed using descriptive and inferential statistics and validity and reliability were assessed using Cronbach's alpha. Cronbach's alpha was used to assess the internal consistency of the measurement items, with values above 0.70 considered to be reliable, as recommended by Mewomo, Ndlovu and Iyiola (2022). The obtained data demonstrated high reliability (Cronbach's alpha = 0.901), making it suitable for the subsequent analysis. Statistical Package for the Social Sciences (SPSS) version 30 (IBM Corp., Armonk, NY, US) was used for data analysis, incorporating mean scores (MS), the Kruskal-Wallis test and exploratory factor analysis. Data normality was assessed using the Shapiro-Wilk test and the Kruskal-Wallis H-test was used to detect significant differences across the respondent categories. Factor analysis (FA) was employed to classify the main drivers of SWM into distinct categories.

RESULTS AND DISCUSSION

Demographic Characteristics of Respondents

Table 2 shows the demographic details of the respondents, with a total number of 195 responses. Specifically, 39.0% (n = 76) were based in Johannesburg, 28.7% (n = 63) in Durban and 30.3% (n = 56) in Port Elizabeth. A substantial proportion of respondents (50.3%) held a master's degree. Additionally, the respondents possess significant experience and professional expertise in managing and executing construction projects, with 9 (4.6%) having up to 5 years of experience in the construction industry, 57 (29.2%) have more than 5 years but less than 10 years, 41 (21.0%) between 11 and 15 years and 88 (45.1%) with more than 16 years of experience. These figures suggest that the respondents were sufficiently skilled and experienced to provide reliable survey responses.

Table 2. Respondents' demographic information

Demographic Characteristics		Frequency (n = 195)	%
Level of education	Bachelor's degree	34	17.4
	Bachelor's honours degree	46	23.6
	Master's degree	98	50.3
	Doctorate (PhD)	17	8.7
Location	Johannesburg	76	39.0
	Durban	63	28.7
	Port Elizabeth	56	30.3
Area of expertise	Architect	25	12.8
	Construction manager	54	27.7
	Project manager	63	32.3
	Quantity surveyor	28	14.4
	Civil engineer	25	12.8
Years of experience	1 year to 5 years	9	4.6
	6 years to 10 years	57	29.2
	11 years to 15 years	41	21.0
	16 years to 20 years	70	35.9
	More than 20 years	18	9.2

Ranking of Socio-economic Drivers of Smart Waste Management Implementation

The ranking of the 25 socio-economic drivers for SWM implementation in South Africa's construction industry is presented in Table 3. A one-sample t-test was conducted using a test value of 3.5. The results indicated that most socio-economic drivers were statistically significant ($p < 0.05$), consistent with the benchmarks used in previous studies such as Olanrewaju et al. (2020). The MS ranged between 4.32 and 3.52, all of which were above the 3.50 threshold, highlighting the importance of these socio-economic drivers in supporting SWM adoption.

Table 3. MS ranking of the identified socio-economic drivers

	Mean	SD	Test Value = 3			Significant ($p < 0.05$)
			t	df	Sig. (2-tailed)	
DR1	4.32	0.844	11.899	194	0.001	Yes
DR2	4.30	0.870	13.306	194	0.001	Yes
DR3	4.27	1.000	10.860	194	0.001	Yes
DR4	4.10	0.995	9.978	194	0.001	Yes
DR5	4.08	1.007	12.081	194	0.001	Yes
DR6	3.99	0.977	20.831	194	0.001	Yes
DR7	3.96	1.072	15.479	194	0.001	Yes
DR8	3.93	0.980	15.006	194	0.001	Yes
DR9	3.93	1.070	10.199	194	0.001	Yes
DR10	3.92	1.168	10.694	194	0.001	Yes
DR11	3.90	1.043	12.564	194	0.001	Yes
DR12	3.89	1.047	14.227	194	0.001	Yes
DR13	3.87	1.121	12.180	194	0.001	Yes
DR14	3.82	1.071	21.798	194	0.001	Yes
DR15	3.80	1.120	5.559	194	0.001	Yes
DR16	3.79	1.088	7.034	194	0.001	Yes
DR17	3.71	1.235	7.176	194	0.001	Yes
DR18	3.68	1.317	6.156	194	0.001	Yes
DR19	3.65	1.293	6.270	194	0.001	Yes
DR20	3.63	1.259	8.060	194	0.001	Yes
DR21	3.59	1.338	6.390	194	0.001	Yes
DR22	3.57	1.255	10.974	194	0.001	Yes
DR23	3.55	1.211	17.682	194	0.001	Yes
DR24	3.53	1.237	6.997	194	0.001	Yes
DR25	3.52	1.303	3.903	194	0.001	Yes

Notes: n = 195; MS: Mean score of the identified socio-economic drivers to SWM, SD: Standard deviation, df: Degree of freedom

As presented in Table 3, the identified socio-economic drivers ranged from "Availability and investment in digital infrastructure" (MS = 4.32; standard deviation [SD] = 0.844; t = 11.899; df = 194; Sig. = 0.001), which had the highest rank, to "Availability of employment opportunities through SWM initiatives"

(MS = 3.52; SD = 1.303; t = 3.903; df = 194; Sig. = 0.001), which was ranked the lowest. This indicates that all identified socio-economic drivers are crucial to the effective implementation of SWM and should be considered collectively to achieve optimal results.

Several studies have explored factors influencing SWM adoption in the built environment. Zhang et al. (2019) and Iyiola, Shakantu and Daniel (2024) identify digital infrastructure as a key enabler of innovation, yet it remains insufficient in supporting SWM in construction. Access to accurate, real-time data through digital platforms enhances decision-making and facilitates implementation (Fatimah et al., 2020). Effective SWM also requires appropriate technologies for waste collection, segregation, recycling and disposal. Financial performance is another critical determinant. High investment, operational and maintenance costs, along with limited funding, can hinder adoption. Zhang et al. (2019) emphasise the importance of effective cost planning, while Yadav, Soni and Kumar (2023) and Iyiola, Shakantu and Daniel (2024) note that high start-up costs often discourage small and medium-sized firms. Additionally, clear policies and strong regulatory frameworks are essential in developing countries, as they promote compliance, provide guidance and create an enabling environment for improved waste management systems.

Kruskal-Wallis Test (One-way Analysis of Variance [ANOVA])

The Kruskal-Wallis one-way ANOVA was used to examine whether respondents' professional backgrounds influenced their perceptions of the importance of these socio-economic drivers for SWM implementation. The Shapiro-Wilk test was first used to assess normality, thereby justifying the non-parametric approach. As shown in Table 4, most drivers produced p-values above 0.05, indicating no statistically significant differences ($p > 0.05$) in the ranking of all 25 socio-economic drivers across professional backgrounds. This suggests strong consensus among respondents, regardless of their professional backgrounds. The architects ranked DR14, "Efficient communication and information flow among project teams", as most significant, with a MS of 4.40. Construction managers and civil engineers identified DR6, "Stakeholders' collaboration and engagement in SWM initiatives", as the most crucial driver. The project managers and quantity surveyors prioritised DR23, "Workforce training and capacity building for Industry 4.0 skills". Likewise, civil engineers highlighted DR4, "Development of SWM policies and regulations", as the most significant socio-economic driver.

Table 4. Kruskal-Wallis test analysis of the socio-economic drivers

Code	Architect		Construction Manager		Project Manager		Quantity Surveyor		Civil Engineer		Shapiro-Wilk (*p*-Value)	Kruskal-Wallis		Remark
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank		(χ^2)	Sig.	
DR1	3.68	14	3.85	12	4.05	5	3.75	18	3.96	11	0.000	5.931	0.204	$p > 0.05$
DR2	3.64	16	3.76	16	4.14	4	4.04	8	3.96	11	0.000	6.751	0.150	$p > 0.05$
DR3	3.80	9	3.78	15	3.89	10	4.04	8	3.92	13	0.000	0.528	0.971	$p > 0.05$
DR4	3.68	14	3.81	13	3.71	18	3.89	13	4.00	10	0.000	1.887	0.757	$p > 0.05$
DR5	3.84	7	3.87	11	3.89	10	3.82	14	4.16	5	0.000	2.480	0.648	$p > 0.05$
DR6	4.20	2	4.48	1	4.29	3	4.07	7	4.28	1	0.000	5.729	0.220	$p > 0.05$
DR7	3.88	6	4.31	2	4.02	6	4.04	8	4.16	5	0.000	6.418	0.170	$p > 0.05$
DR8	4.08	4	4.11	5	3.95	7	4.21	3	4.20	2	0.000	1.953	0.744	$p > 0.05$
DR9	3.72	12	3.80	14	3.62	19	4.18	4	3.88	17	0.000	4.914	0.296	$p > 0.05$
DR10	3.56	19	3.93	9	3.76	17	3.93	12	3.88	17	0.000	2.441	0.655	$p > 0.05$
DR11	3.76	10	4.00	7	3.87	12	4.11	5	4.16	7	0.000	1.976	0.740	$p > 0.05$
DR12	3.64	16	4.06	6	3.95	7	4.11	5	4.20	2	0.000	5.304	0.25	$p > 0.05$
DR13	3.84	7	3.98	8	3.90	9	3.82	14	4.12	8	0.000	2.362	0.670	$p > 0.05$
DR14	4.40	1	4.31	2	4.37	2	4.25	2	4.20	2	0.000	1.675	0.795	$p > 0.05$
DR15	3.28	24	3.48	21	3.32	25	3.79	17	3.84	19	0.000	5.165	0.271	$p > 0.05$

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Table 4. *Continued*

Code	Architect		Construction Manager		Project Manager		Quantity Surveyor		Civil Engineer		Shapiro-Wilk (p-Value)	Kruskal-Wallis		Remark
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank		(χ^2)	Sig.	
DR16	3.52	21	3.35	25	3.86	14	3.64	19	3.92	13	0.000	4.837	0.304	$p > 0.05$
DR17	3.56	19	3.46	22	3.86	14	3.82	14	3.64	24	0.000	3.336	0.503	$p > 0.05$
DR18	3.60	18	3.67	18	3.40	24	3.57	22	3.92	13	0.000	2.613	0.624	$p > 0.05$
DR19	3.72	12	3.37	23	3.54	21	3.64	19	3.64	24	0.000	2.093	0.719	$p > 0.05$
DR20	3.52	21	3.72	17	3.78	16	3.61	21	3.84	19	0.000	1.361	0.851	$p > 0.05$
DR21	3.76	10	3.67	18	3.41	22	3.46	23	3.72	23	0.000	2.315	0.67	$p > 0.05$
DR22	4.08	4	3.89	10	3.87	12	4.04	8	3.80	21	0.000	1.676	0.795	$p > 0.05$
DR23	4.12	3	4.17	4	4.43	1	4.54	1	3.92	13	0.000	5.213	0.266	$p > 0.05$
DR24	3.40	23	3.67	18	3.62	19	3.43	24	4.04	9	0.000	4.623	0.328	$p > 0.05$
DR25	2.92	25	3.37	23	3.41	22	3.29	25	3.76	22	0.000	5.075	0.280	$p > 0.05$

Result of Exploratory Factor Analysis

The dataset's suitability for factor analysis was evaluated using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity. The KMO statistic, which ranges from 0 to 1, indicates the sampling adequacy, with higher values reflecting greater suitability (Pallant, 2020). As shown in Table 5, a KMO value of 0.793 confirms that the data is highly appropriate for FA. Bartlett's test assesses whether the variables are sufficiently correlated to perform FA. The test result, a Chi-square value of 3026.833 with 300 degrees of freedom, was statistically significant, demonstrating meaningful correlations among variables and supporting the dataset's suitability for FA.

Table 5. KMO and Barlett's test of sample adequacy

KMO Measure of Sampling Adequacy	Bartlett's Test of Sphericity	
0.793	Approx. chi-square	3,026.833
	df	300.000
	Sig.	–

This study employed principal component analysis with varimax rotation and Kaiser normalisation to analyse the socio-economic drivers, with Table 6 showing the total variance explained. The table includes the initial eigenvalues and rotation sums of the squared loadings, illustrating each component's contribution to the total variance. Variables were retained based on a factor loading criterion of 0.50, as suggested by Field (2024).

The rotated factor matrix for the 25 socio-economic drivers is displayed in Table 6. The scree plot in Figure 1 guided the extraction of six components, which together accounted for 70.203% of the total variance across the 25 variables. The individual variance contributions were: Component 1 (20.052%), Component 2 (15.547%), Component 3 (10.885%), Component 4 (9.803%), Component 5 (8.964%) and Component 6 (4.953%). Based on the patterns of relationships among the variables in each component, the components were named as follows:

1. Component 1 – Financial and Resource Efficiency Drivers.
2. Component 2 – Environmental Sustainability Drivers.
3. Component 3 – Policy and Regulatory Drivers.
4. Component 4 – Organisational and Managerial Drivers.
5. Component 5 – Social and Human Capital Drivers.
6. Component 6 – Stakeholders' Collaboration Drivers.

Table 6. Factor analysis of the identified drivers

Code	Component						Drivers	% of Variance	Cumulative %
	1	2	3	4	5	6			
DR1	0.811						Financial and resource efficiency drivers	20.052	20.052
DR3	0.727								
DR5	0.795								
DR2	0.778								
DR18	0.851								
DR13	0.800								
DR12	0.759								
DR6		0.868					Environmental sustainability drivers	15.547	35.599
DR10		0.834							
DR7		0.882							
DR8		0.879							
DR4			0.655				Policy and regulatory drivers	10.885	46.484
DR17			0.797						
DR16			0.781						
DR19			0.584						
DR9			0.685						

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Table 6. *Continued*

Code	Component						Drivers	% of Variance	Cumulative %
	1	2	3	4	5	6			
DR11				0.869			Organisational and managerial drivers	9.803	56.286
DR15				0.882					
DR14				0.867					
DR23					0.658		Social and human capital drivers	8.964	65.250
DR22					0.804				
DR21					0.653				
DR25					0.614				
DR24						0.631	Stakeholders' collaboration drivers	4.953	70.203
DR20						0.602			

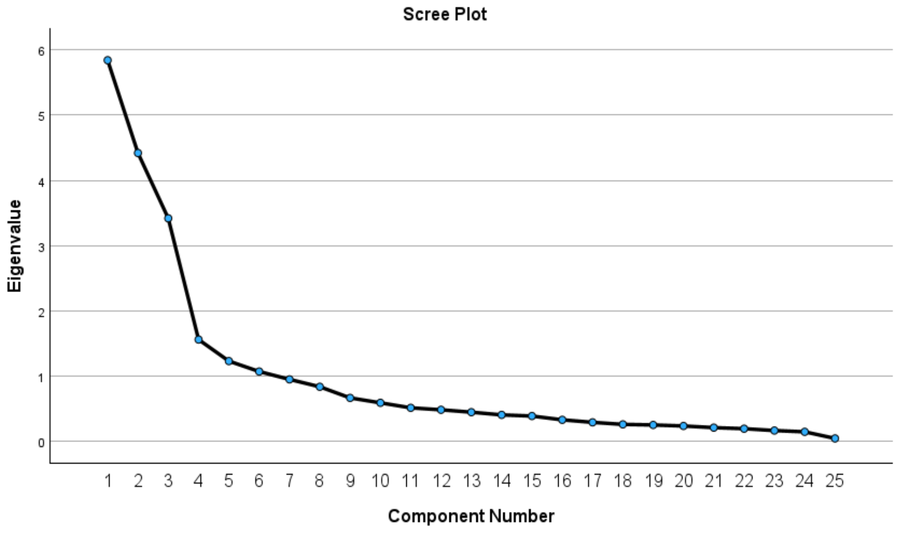

Figure 1. Scree plot for the identified drivers

Component 1: Financial and Resource Efficiency Drivers

Table 6 indicates that "financial and resource efficiency drivers" are the most influential socio-economic drivers of SWM implementation. This dimension comprises seven interrelated factors:

1. Investment in digital infrastructure.
2. Financial and technical support.
3. Reduced operational costs.
4. Affordable waste services.
5. Efficient material utilisation.
6. The integration of SWM into project planning.
7. Effective on-site coordination.

The availability and investment in digital infrastructure significantly enhance SWM performance by enabling real-time waste tracking, automated monitoring and the accurate assessment of material usage, thereby supporting data-driven decision-making and reducing inefficiencies (Elghaish et al., 2022; Iyiola and Mewomo, 2024). Financial and technical support are equally critical, particularly in developing contexts where firms face funding and expertise constraints (Zhang et al., 2019; Yadav, Soni and Kumar, 2023). Lower operational costs and affordable waste services further motivate firms to adopt SWM practices (Fatimah et al., 2020). Moreover, efficient resource use and the early integration of SWM into project planning promote waste minimisation from the design stage (Bakchan, Faust and Leite, 2019). The effective coordination of SWM activities on construction sites also improves workflow, compliance and overall project performance (Abkar et al., 2024).

Component 2: Environmental Sustainability Drivers

Environmental sustainability drivers encompass reducing landfill waste and pollution, lowering carbon footprints, promoting recycling and circular economy practices and ensuring the sustainable use of natural resources. The findings show that minimising landfill disposal is a key motivator of improved waste management practices, as landfilling contributes to soil contamination, water pollution and greenhouse gas emissions (Yang et al., 2017; Chen et al., 2022b). This aligns with the study of Islam et al. (2019), who found that proper sorting, recycling and reuse significantly reduce environmental impacts. Lowering carbon emissions also drives sustainable waste practices. Reusing and recycling construction materials reduces the demand for new material production, thereby lowering energy consumption and emissions. Wang, Li and Yang (2020) reported that recycling can reduce construction-related carbon emissions by up to 30%, depending on material type. Promoting recycling and circular economy principles encourages keeping materials in use longer, reducing waste and costs (Yadav, Soni and Kumar, 2023; Zhang et al., 2023). Lastly, the findings confirm that the sustainable use of natural resources drives companies to adopt greener waste management methods. The careful use of raw materials reduces the pressure on natural ecosystems and supports global sustainability goals. This corroborates the study by Almusaed et al. (2024), which showed that resource-efficient construction reduces environmental degradation and improves project resilience.

Component 3: Policy and Regulatory Drivers

Policy and regulatory drivers are crucial in shaping the adoption and implementation of SWM practices in the construction industry. This study found that the development of SWM policies and regulations is a major motivator, as clear rules provide guidance, create uniform waste handling practices, reduce illegal dumping and encourage recycling (Chen, Hua and Liu, 2019; Zhang et al., 2019). Strong waste laws increase the likelihood that firms follow environmentally responsible practices. Government incentives and funding support also significantly influence SWM adoption. Grants, subsidies, tax breaks and funding for green technologies reduce the financial burden of implementing technologies such as digital tracking systems, recycling equipment and waste treatment facilities, while promoting innovation (Zhang et al., 2019; 2023). Institutional frameworks for monitoring and evaluation ensure policies are effectively enforced and companies are accountable for waste generation and disposal (Iyiola, Shakantu and Daniel, 2024). Without proper monitoring, even well-designed policies may fail to achieve intended outcomes. Public-private partnerships play a vital role by sharing the responsibilities among government bodies, contractors and waste agencies, enhancing technical capacity, improving efficiency and ensuring the practical enforcement of regulations (Tanveer et al., 2025). Finally, compliance with environmental standards motivates firms to adopt systematic, sustainable waste management practices, supporting continuous improvement, resource efficiency and responsible handling. Collectively, these policy and regulatory drivers create an enabling environment for effective SWM in the construction sector.

Component 4: Organisational and Managerial Drivers

The findings highlight that organisational and managerial drivers play a vital role in determining how construction companies adopt and implement SWM practices. These drivers influence the internal structures, behaviours and decision-making processes that directly affect the success of sustainability initiatives on construction sites. One significant finding is that the "leadership and management commitment to innovation" is a strong motivator for improving SWM implementation. Gledson et al. (2024) mentioned that when leaders actively support new ideas, allocate resources and encourage the use of digital technologies, employees become more willing to adopt better waste practices. This aligns with the study by Iyiola, Shakantu and Daniel (2024), which found that strong leadership provides clear direction and ensures that sustainability goals are integrated into project activities. The study also found that the "promotion of a sustainability and innovation-oriented organisational culture" significantly influences waste management outcomes. Organisations that prioritise sustainability often integrate eco-friendly practices into their policies, routines and decision-making processes. This commitment fosters innovation and enables employees to more easily explore new waste-reduction strategies, digital solutions and circular economy practices. Such cultures also promote accountability and teamwork, both of which are necessary for effective waste management. Another key finding relates to the importance of "efficient communication and information flow among project teams". When information moves smoothly across teams, waste processes become more coordinated and efficient. Effective communication ensures that everyone understands their roles in waste sorting, recycling and disposal. In the context of SWM, it ensures that waste guidelines are followed correctly and that any problems are addressed quickly.

Component 5: Social and Human Capital Drivers

These drivers focus on the skills, awareness and participation of people within the sector, showing that effective SWM depends not only on technologies and policies but also on human capabilities and social support systems. A key finding is that "workforce training and capacity building for Industry 4.0 skills" greatly influences the adoption of SWM practices. As construction companies adopt digital transformation, workers need the skills to operate and manage these technologies effectively. Training improves technical competence and reduces resistance to new methods (Iyiola, Shakantu and Daniel, 2024). This finding supports previous research showing that continuous skill development enhances innovation and improves waste minimisation efforts on construction sites. Without adequate training, even advanced systems may fail to deliver meaningful results (Yadav, Soni and Kumar, 2023). This study highlights the importance of "knowledge sharing and continuous improvement strategies among professionals". When professionals exchange experiences, lessons learned and best practices, the entire sector benefits. Knowledge sharing helps to identify effective waste management techniques, encourages innovation and prevents repeated mistakes (Adepoju and Aigbavboa, 2021). This process helps to foster a culture that values improvement and innovation. Another significant finding relates to "improved awareness and perception of SWM in construction". When workers, managers and stakeholders understand the environmental and economic benefits of proper waste management, they are more likely to support and participate in sustainable practices (Marimuthu et al., 2021). Lastly, the study found that the "availability of employment opportunities through SWM initiatives" serves as an essential motivator. The growth of the recycling industry and waste-sorting centres and the adoption of green technology, could create new jobs, encouraging communities and workers to engage in waste management activities (Rafiq et al., 2025).

Component 6: Stakeholders' Collaboration Drivers

Stakeholders' collaboration drivers play an essential role in improving SWM practices in the construction industry. These drivers emphasise collective action and shared responsibility, which support more effective and coordinated waste management. When contractors, clients, consultants, government agencies and waste service providers work together, waste reduction strategies become more practical and easier to implement (Rodrigo et al., 2024). Collaboration helps to align expectations, share responsibilities and encourage joint problem-solving. This finding of Senaratne et al. (2023) affirmed that strong stakeholder involvement leads to better project outcomes and improves the adoption of sustainable waste strategies. Collaboration also helps build trust and ensures that decisions take into account social, environmental and economic impacts.

Research Implications

This study contributes to SWM knowledge by empirically identifying and categorising multidimensional socio-economic drivers influencing its adoption in the construction industry. Unlike previous studies that examine determinants in isolation, this research consolidates them into six interconnected dimensions, offering a structured, context-specific framework for developing economies. By integrating financial, institutional, organisational, social and sustainability perspectives, it advances theoretical discussions on technology adoption and sustainable construction management and provides a foundation for future digital sustainability research. For construction professionals, the findings highlight that effective SWM requires more than technological investment. Strategic planning, leadership commitment, workforce capacity development and cross-functional coordination are essential. The digital infrastructure must be supported by operational frameworks, training and internal policies that embed SWM into project planning. Stakeholder collaboration and knowledge sharing further enhance efficiency, resource use, cost reduction and environmental performance, enabling firms to gain a competitive advantage. At the policy level, the study underscores the need for supportive institutional frameworks, enforcement mechanisms and incentive schemes to accelerate SWM adoption. Effective implementation can reduce landfill waste, lower carbon emissions, improve environmental quality and promote circular economy practices. Human capital development through SWM also supports job creation and the enhancement of digital skills, contributing to sustainable economic growth in developing countries.

CONCLUSION

Effective waste management in developing countries can be enhanced through SWM, provided that key adoption barriers are addressed. This study examined and validated the critical drivers of SWM implementation, all of which were found to be statistically significant. These drivers were grouped into six categories: financial and resource efficiency, environmental sustainability, policy and regulation, organisational and managerial, social and human capital, and stakeholder collaboration. Addressing these interconnected factors is essential for successful SWM implementation in South Africa and similar developing contexts. Using a questionnaire survey focused on construction professionals, this study has identified the key determinants shaping SWM adoption in the South African construction industry.

Future studies may employ a qualitative approach, using semi-structured interviews with experienced construction practitioners, to complement the quantitative findings by exploring the contextual and practical factors underlying the identified drivers that the structured questionnaires may not fully capture. SWM implementation can enhance productivity, reduce material waste, stimulate economic growth and expand the pool of digitally skilled workers. However, achieving these benefits requires a shift in stakeholder mindset, targeted capacity-building initiatives, strong professional training, supportive policies, reliable digital infrastructure, effective leadership and active collaboration. Although this study was based on careful and rigorous analysis, certain limitations should be acknowledged. Avenues for future research may emerge. The research primarily focused on SWM within the broader framework of circular economy practices. Other dimensions, such as production processes, consumption patterns and resource recovery systems, also play a critical role in advancing circular economy implementation in South Africa. Future research could therefore explore how the identified socio-economic drivers of SWM contribute to the implementation of circular economy practices in other areas. Further studies may examine these drivers within developed-country contexts and compare the findings with those reported in this study. Given that SWM infrastructure, regulatory environments and technological capacity differ significantly between developed and emerging economies, comparative investigations could reveal both shared and context-specific drivers. Such insights would help in developing a more adaptable and dynamic framework to guide firms operating across diverse economic and institutional settings.

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