DIGITAL TECHNOLOGIES AND THEIR APPLICATIONS TO REVERSE LOGISTICS OF ORGANIC SOLID WASTE: ANALYSIS FOR THE BRAZILIAN CONTEXT USING THE LAWSHE METHOD

1. INTRODUCTION

Reverse logistics (RL) of Municipal Solid Waste (MSW) enables the return of materials to the production cycle (Leal *et al*., 2024). Organic Solid Waste (OSW) represents both the greatest challenge and opportunity: in 2023, only 0.4% was destined for composting, despite its potential to be transformed into agricultural and energy inputs. Alternatives such as biomethane production reinforce the key role of OSW in the transition toward a circular model (ABREMA, 2024).

Digital Technologies (DTs) are fundamental to OSW management. Artificial intelligence (AI) and machine learning optimize composting and predict waste generation (Ali *et al*., 2024; Bag *et al*., 2024; Gupta *et al*., 2024). IoT enables real-time monitoring (Shetty *et al*., 2024), and Big Data identifies waste patterns and supports circular models (Bag *et al*., 2024; Shetty *et al*., 2024). Blockchain ensures traceability and transparency (Bag *et al*., 2024; Shetty *et al*., 2024), while digital twins allow predictive maintenance of equipment (Cappelletti; Menato, 2023).

The main challenges of OSW RL involve waste heterogeneity, volume variability, tracking failures, and lack of infrastructure (Ali *et al*., 2024). Additional barriers include poor data quality, difficulties in model interpretation, and high costs (Fang *et al*., 2023), as well as fragmentation and predictive uncertainty (Gupta *et al*., 2024).

DTs offer solutions aligned with these problems: AI for prediction and optimization, IoT for monitoring, Big Data for data integration, blockchain for reliability, and digital twins for extending equipment lifespan.

Recent literature addresses DTs in MSW management in general, without a specific focus on OSW. Studies highlight AI (Ali *et al*., 2024; Bag *et al*., 2024; Gupta *et al*., 2024), IoT and Big Data (Shetty *et al*., 2024), blockchain (Bag *et al*., 2024; Shetty *et al*., 2024), and digital twins (Cappelletti; Menato, 2023). However, no investigation has systematically validated expert perceptions regarding the essentiality of these technologies in OSW RL within a given context.

This study applies the Lawshe method (1975) to quantify expert consensus, representing an original contribution. It seeks to identify which DTs are perceived as essential for OSW RL, combining systematic review and expert insights in Brazil, thus supporting innovation policies and strategies.

2. RESEARCH PROBLEM AND OBJECTIVE

Despite the growing body of literature on DTs applied to waste management and the circular economy, most studies focus on MSW in general, without exclusive emphasis on OSW. None of the reviewed investigations sought to systematically validate expert perceptions regarding the essentiality of different DTs specifically applied to OSW RL. Thus, a structured effort to deeply assess the relevance of these technologies for OSW RL remains absent.

Given this gap, this research seeks to answer: which DTs are already available and in what applications are they being used to enable OSW RL? Which of these DTs would be most appropriate to overcome OSW RL challenges in the Brazilian context?

Therefore, the aim of this study is to identify the DTs already available and their applications in OSW RL, and to validate them for the Brazilian context through content validity analysis based on Lawshe's method (1975), combining a systematic literature review with the collection of insights from Brazilian experts.

3. METHODOLOGIES

For this research, four main stages were followed: conducting a systematic literature review using the PRISMA method, which organizes the process into four phases—Identification, Screening, Eligibility, and Inclusion (Galvão, Pansani, and Harrad, 2015); defining the respondents' profile and structuring the data collection form; applying the data collection; and finally, performing quantitative content validity analysis based on Lawshe's method (1975).

In the systematic review, conducted in the Scopus and Web of Science databases with a time frame of 2023–2024, 272 articles were identified. After exclusions, 175 remained for screening and, subsequently, 148 for full reading. From this analysis, 9 DTs with potential application in OSW RL were identified.

Based on this, a questionnaire was designed in Google Forms divided into four sections: introduction; respondent profile; evaluation of DTs on an ordinal scale (essential, important, not important); and acknowledgments. Respondents were selected according to practical and/or academic experience, covering seven professional profiles (academics, public sector, waste companies, engineers, developers, NGOs, and consultants). Prospection was carried out via LinkedIn, ensuring diversity of perspectives.

The data were analyzed using Lawshe's method (1975), which measures expert consensus regarding the essentiality of DTs through the Content Validity Ratio (CVR). From mean, variance, standard deviation, and critical values (Table 1), items with greater consensus were identified, refining the instrument and confirming its coherence with the research objectives.

Table 1 – Lawshe Formulas

Formulas		Description of Variables
Equation 1 – Content Validity Ratio	$CVR = \frac{ne - \frac{N}{2}}{\frac{N}{2}}$	ne: number of experts who rated the criterion as "Essential"; N: total number of experts who participated in the study.
Equation 2 – Mean **Equation 3 – Variance** **Equation 4 – Standard Deviation**	$\mu = n \times p$ $\sigma^2 = n \times p \times (1-p)$ $\sigma = \sqrt{n \times p \times (1-p)}$	"n" is the number of respondents and "p" is the probability of rating the item as essential.
Equation 5 – necritical	$necritical = \mu + z \times \sigma$	Significance level 5%, in the standard normal distribution, where z = 1.96.
Equation 6 – CVRcritical	$CVR_{critical} = \frac{necritical - \frac{N}{2}}{\frac{N}{2}}$	N: total number of experts who participated in the study.

Source: Adapted from Lawshe (1975).

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1. DESCRIPTIVE ANALYSIS OF THE DATABASE

The survey initially had 33 respondents (response rate of 32%), resulting, after screening, in 27 valid responses. The absence of technology developers was noted, with academics/researchers (34%) and sustainability consultants/experts (27%) being predominant. NGOs and the public sector had lower participation (3% each).

Regarding professional experience, 45.5% had up to 5 years of activity, while only 21.3% had more than 10 years, revealing a predominance of early-career professionals. Regionally, there was a concentration in the Southeast (63.6%), with low participation from the Center-West, North, and Northeast regions (21.3% in total), highlighting the need for greater territorial representativeness in future research.

4.2. LAWSHE ANALYSIS FOR VALIDATION OF DIGITAL TECHNOLOGIES IN ORGANIC WASTE RL

The Lawshe method (1975) was applied with 27 specialists. The statistical parameters calculated (Table 2) indicated critical CVR = 0.377. For validation, the CVR of the functionalities should be ≥ this value.

Table 2 – Calculated Statistical Parameters

Statistical Parameter	Value
Mean	13.5
Variance	6.75
Standard Deviation	2.598
Total respondents (n)	27
Critical ne	18.592
Critical CVR	0.377

Source: Authors (2025).

None of the nine evaluated functionalities (Table 3) reached the validation threshold. Despite this, three presented positive CVRs: AI in waste generation forecasting (0.111), IoT in traceability (0.259), and Big Data in machinery maintenance (0.259). Although not validated, the literature recognizes their practical potential but also highlights barriers such as costs, limited infrastructure, and low familiarity among specialists, which explains the conservative evaluation.

Table 3 - Validation of Digital Technologies for Organic Waste RL

Digital Technology Functionality	CVR	ESSENTIAL Count	Validation
AI in decomposition monitoring	-0.630	5	Not Validated
AI in composting optimization	-0.407	8	Not Validated
AI in waste generation forecasting	0.111	15	Not Validated
IoT in predictive equipment maintenance	-0.111	12	Not Validated
IoT in organic waste traceability	0.259	17	Not Validated

IoT in transforming organic waste into value-added products	0.037	14	Not Validated
Big Data in machinery maintenance	0.259	17	Not Validated
Blockchain in circular economy and waste management	0.037	14	Not Validated
Blockchain in integration with other technologies	-0.037	13	Not Validated

Source: Authors (2025).

4.3. DISCUSSION OF DIGITAL TECHNOLOGIES WITH POSITIVE CVR

Three DTs presented positive CVR values below the essentiality threshold: AI in waste generation forecasting (0.111), IoT in organic waste traceability (0.259), and Big Data in machinery maintenance (0.259). Despite this, the literature points to critical factors influencing the effectiveness of these technologies, requiring a review of the state of the art for a more detailed analysis of implementation conditions in organic waste management in the Brazilian context.

For AI in waste forecasting, Fang *et al.* (2023) highlight models with neurais networks, linear regression, decision trees, and genetic algorithms, as well as forecasting of biogas and CO_2. Gupta *et al.* (2024) mention applications in predicting biogas efficiency and recoverable nutrients. Barriers include extrapolation of laboratory data, skepticism about accuracy, low interpretability of models, and high computational demand. These factors explain the low CVR obtained.

Regarding IoT in organic waste traceability, Cappelletti & Menato (2023) and Bag *et al.* (2024) affirm that it enables detailed tracking, optimizing recycling and reuse. However, high costs and the requirement of robust infrastructure limit its adoption. Public policies and incentives may facilitate implementation.

For Big Data, Cappelletti & Menato (2023) highlight predictive maintenance and real-time monitoring, but costs, infrastructure, and lack of training hinder immediate application (Shetty *et al.*, 2024; Bag *et al.*, 2024). Government funding programs and incentives are pointed out as enablers.

In summary, the limiting factors discussed help interpret professionals' judgment: values below the threshold do not invalidate the applicability of DTs but reflect considerations about the national socioeconomic context.

4.4. DISCUSSION OF DIGITAL TECHNOLOGIES WITH NEGATIVE CVR

Three DTs presented negative CVRs. In the case of AI, functionalities of decomposition monitoring (-0.630) and composting optimization (-0.407) were classified as non-essential, although the literature (Ali *et al.*, 2024; Bag *et al.*, 2024) points to contributions to automation and composting efficiency.

IoT in predictive maintenance (-0.111) was also considered non-essential, although smart sensors are crucial to detect failures and extend equipment lifespan (Cappelletti & Menato, 2023).

The divergence between results and theory may be related to the technical familiarity of evaluators (Lawshe, 1975) and to implementation barriers: costs, infrastructure, training, and institutional resistance (Shetty *et al*., 2024; Bag *et al*., 2024; Ali *et al*., 2024). Further research is recommended with specialists with practical experience in DTs applied to the waste sector.

4.5. DISCUSSION OF DIGITAL TECHNOLOGIES WITH CVR CLOSE TO ZERO

CVRs close to zero for Blockchain in the circular economy and integration with other technologies indicate a lack of consensus on their essentiality. According to Lawshe (1975), such a result may reflect limitations in familiarity or disagreements about maturity and applicability.

The literature, however, points to Blockchain as a tool for transparency, traceability, and reliability (Bag *et al*., 2024; Shetty *et al*., 2024). Barriers include costs, incipient infrastructure, and integration with legacy systems (Cappelletti & Menato, 2023), in addition to dependence on IoT, Big Data, and AI.

Thus, near-zero CVRs reflect an early stage of acceptance; their future use will depend on strengthening digital infrastructure, standardizing protocols, and public policies for digital transformation.

5. FINAL CONSIDERATIONS

The study sought to identify and validate, from the perspective of Brazilian experts, the DTs applicable to OSW RL and their applications. To this end, it combined a systematic literature review with quantitative evaluation using Lawshe's method (1975), allowing the measurement of consensus on the relevance and essentiality of technologies. Thus, it highlighted DTs already available and their suitability for overcoming RL challenges in Brazil, contributing both to academic advancement and to innovation strategies.

The contributions occur in two dimensions. In the theoretical field, a framework with 9 DTs and their functionalities was proposed, serving as a basis for future research. Methodologically, the use of Lawshe's method provided an alternative and robust statistical validation. In the practical field, no functionality was validated, possibly due to barriers such as high implementation costs and incipient digital infrastructure. Furthermore, the absence of technology developers on the panel may have limited the technical assessment, favoring more conservative positions. Still, DTs such as IoT (traceability), Big Data (equipment maintenance), and AI (waste prediction) were considered essential but not validated, pointing to paths for future investigations.

Among the limitations, the profile of participants and the language used stand out, as it could have been more explicit regarding DTs and their functionalities. As a continuity, it is recommended to expand the sample of evaluators, include technology developers, apply the framework in different territorial contexts, and deepen the analysis of economic, social, and environmental impacts of digitalization in the management and valorization of OSW, especially in composting and energy recovery.

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