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Digital Transformation in Waste Management: Disruptive Innovation and Digital Governance for Zero-Waste Cities in the Global South as Keys to Future Sustainable Development

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Abstract: Waste is a complex challenge that requires collaboration between multiple stakeholders to achieve a circular economy. In this context, there is a growing demand for digital solutions that integrate physical and digital infrastructure to create digital waste governance systems. Analog management, without accurate data, is becoming increasingly unfeasible in light of the UN Sustainable Development Goals. Tools such as online geographic information systems (WebGIS) allow the collection and integration of large volumes of physical and human data and the establishment of a digital governance structure that brings together different technologies, tools and methods in the same environment. This article aims to present the State of the Art on the topics of zero-waste cities, WebGIS, and disruptive innovation. The article starts from the hypothesis that only a process of disruptive and systemic innovation in the value chain and urban solid waste management (MSWMS), supported by the principle of zero-waste cities, circular economy and webGIS, can effectively help to solve this problem. The research uses an exploratory literature review on the concepts of zero-waste cities, systemic innovation and webGIS applied to waste management, linking them to the theoretical framework of sustainability as a science and to Brazilian public policies, such as the National Solid Waste Policy (Law 12.305/2010), the National Circular Economy Policy (Law 1.874/2022) and the National Digital Government Strategy of Brazil 2024–2027 (ENGD). As a result, scientific publications on zero-waste cities increased from 2018 to 2023 and several countries have adopted zero-waste guidelines in waste management policies. WebGIS, remote sensing, geoprocessing and different technologies are increasingly being incorporated into waste management, generating significant impacts on the diversion of resources from landfills, mitigating climate change, and generating and/or adding value to the useful life of waste and garbage resources, in addition to the optimization and efficiency of collection operators and citizen engagement in public policies. Disruptive innovation has proven to be a concrete process to enable the transition from obsolete sociotechnical systems (such as the linear economy), where sustainable finance and environmental entities play a fundamental role in orchestrating and coordinating the convergence of private, public and civil society actors towards this new sustainable development paradigm. The case study proved to be fruitful in proposing and encouraging the adoption of such methods and principles in municipal waste management, allowing us to outline a first conception of a digital government structure and digitalization of public services for zero-waste cities, as well as pointing out the difficulties of implementing and transforming these systems. This digital governance structure demonstrates the possibility of being replicable and scalable to other cities around the world, which can

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materialize an important tool for the implementation, articulation and development of a long-term sustainable development paradigm, based on the vision of the circular economy and zero-waste cities.

Keywords: circular economy; zero-waste cities; municipal solid waste management systems (MSWMS); disruptive and systemic innovation; digital government; sustainable development

1. Introduction

The anthropocentric phenomenon of the uncontrolled production of solid waste constitutes one of the biggest problems in the sustainable territorial development of cities, countries, regions and, on a larger scale, the terrestrial biota. A phenomenon intrinsically linked to the socio-technical-economic dimension, it is the interface between productive systems, consumption, the construction of urban space and the extraction, manufacture and disposal of natural resources from the Earth [1–3].

The debate about the impossibility of infinite economic growth, based on the linear conception of the economy, is gaining more and more momentum in the international scientific community, which seeks answers and solutions from states, governments and public and private organizations [4,5]. Faced with the inexorability of the impacts on the Earth's natural systems and the planetary limits of this conception of territorial economic development, more than 200 years after the industrial revolution, such institutions are beginning to consensually resonate with the urgency of such a transition to a sustainable model, with close entropy to zero [6–10].

Therefore, municipal solid waste management is a public policy that emerges in response to this negative externality of the economic system. Firstly, optimizing the management of this negative externality; especially with solutions at the cutting edge of the phenomenon [11], whether initially with direct release into the environment, and later with the landfilling of these resources in landfills, controlled landfills, burning and/or transformation into energy (WtE) through combustion or plasma [12].

The concept of a zero-waste city can be defined as an urban model that aims to eliminate waste in landfills or incineration through the practical incorporation of circular economy principles, resource efficiency (production of goods and services) and environmental responsibility. The model foresees a closed-loop system in cities where waste is a resource that is continually recovered, recycled, reused, or not generated at all. This minimizes the amount of waste and maximizes the value of natural resources used in the processes. The zero-waste city fosters a culture of shared responsibility between government, private initiative and civil society, with an emphasis on technological innovation and integrated urban planning [13].

Citizen and community engagement associated with incentives for changes in behavior to root sustainable practices in the population and operation of cities supports a vision of long-term sustainable development aligned with the UN SDGs [14].

So the concept of zero-waste cities precisely challenges the *establishment* of this traditional idea of municipal solid waste management by proposing a radical change in perspective in the formulation of this public policy and the relationship with urban solid waste management as territorial planning that induces systemic and disruptive innovation, given that it proposes a complete transformation of value chains and actions and responsibilities of public and private agents, companies, institutions, organizations and even in the formulation of new materials, products and goods that can be used and reused indefinitely, as the concept of cradle to cradle [3,13,14]

This article aims to present and develop the initial concepts of a digital governance framework for zero-waste cities. It is designed to help cities make the transition to the zero-waste city model and circular economy, facilitating integrated urban planning and increasing citizen and community engagement and participation.

One of the major gaps observed in our research trajectory was the lack of innovative instruments and practices for management and territorial planning on public policies for the management and handling of urban solid waste. In Brazil, the PNRS determines urban waste as an inducer of sustainable development and citizenship. It is precisely this lack of advanced instruments for territorial planning that we want to respond to with this article. The conception of this digital government structure is based on three fundamental concepts.

The design of this digital government structure is supported by three fundamental concepts. The first is the concept of webGIS, online geographic information systems, capable of enabling technological integration and a multitude of data collection, analysis and cross-referencing, among other dimensions. This allows the digital government platform to integrate and coordinate all the actors, processes and structures necessary to transform a city into a zero-waste city. The second is the idea that only a process of disruptive innovation (coordinated by the government) can consolidate the transition to the zero-waste city model and circular economy, which consists of the third fundamental concept (zero-waste city), a process in which the digital government structure can, at the same time, corroborate the implementation, coordination, evaluation and monitoring of this transition.

Achieving zero-waste cities is a challenging vision, as it requires the involvement and commitment of all relevant stakeholders with clear and measurable targets and proper integration of advanced technical solutions with the integration of social technologies (e.g., recycling, behavior changes). It also demands leapfrogging from the current linear system to a circular system through disruptive innovation.

This concept of a zero-waste city with maximum waste recovery and elimination of landfilling and/or burning of resources, translated into a **digital** public policy program for a zero-waste city, finds its means of support and implementation (mobilization, coordination, evaluation) in this digital government structure, whose implementation is and should result in a process of disruptive innovation, fostered by the local government itself (which replaces the established processes of the linear economy). It opens up horizons for sustainable development based on a circular economy and the zero-waste city vision.

The concept of webGIS is intrinsic to the need for planning and managing this sectoral policy in order to encompass all the complexities in a single digital environment linked to space. Thus, we provide examples of the State of the Art of this application in waste management systems combined with other technologies. The concept of zero-waste cities demonstrates the breadth and seriousness with which several countries have been facing this challenge as a strategic issue for the economy and the state. Disruptive innovation concerns how innovation can help cities and regions overcome this complex urban problem, which aims to replace the logic of organization, production, and consumption of the linear economy with the circular economy, generating wealth, jobs and new businesses while also contributing to the mitigation of climate change and the promotion of the SDGs. In this way, we carried exploratory bibliographical research on the term "zero-waste city", We applied webGIS to waste and disruptive and systemic innovation to identify how to solve key challenges for the implementation of the concepts of a zero-waste city and circular economy by formulating a conception based on digital governance. The objective of this research reflects a research gap according to our perceptions about the problem.

We present the results of the application of this concept in the city of Florianópolis, State of Santa Catarina, Brazil. The formalization and publication of online data, indicators

of waste management, along with a first-hand experience of technical and scientific cooperation with the city's government, enabled the validation of some public services related to municipal waste planning and management.

1.1. Legal Context and Analog Government for Complex and Innovative Public Policies

Brazil spent around 20 years discussing the National Solid Waste Policy—PNRS Law nº 12.305 [15]—in the national congress, given the complexity and conflicts of interests between political, economic, social and environmental forces, in addition to the inherent bio-socio-economic diversity of the country. The law brings important and innovative principles, objectives, devices, tools and incentives to a complete transformation in the relationship between agents, public and private actors with the generation, distribution, consumption, handling and management of solid waste in the national territory. It also determines recyclable and reusable solid waste as an economic and social asset and a generator of work and income and a promoter of citizenship (PNRS, Art 6º VIII.) However, even in 2024, the country encounters serious difficulties in concretely advancing the agenda and even fulfilling the initial goals of the law, such as the closure of landfills. It was supposed to occur in 2014 but was postponed to 2021, along with the goal of increasing the recycling rate in municipalities and, consequently, decreasing disposal of natural resources in open-air dumps and/or landfills.

The legal planning and management device for Brazilian municipalities is the Integrated Urban Solid Waste Management Plan—PMGIRS. It is a device in the PNRS's list of instruments in their plan that covers the municipal territory and which coordinates economic and social agents so that they comply with the objectives, principles, guidelines and goals of the PNRS, linked to an investment schedule. It is the municipality, the holder of public services, that must organize territorial planning and manage public contracts and services intended for this purpose. If the political complexity in Brazil were not enough, the formulation of public policies at the municipal and regional level on solid waste management constitutes difficulties in itself, as it represents one of the largest commitments of public money, conflicting interests, large industries and organizations established in the logic of linear production. These are industries established on linear models and technologies with high entropy, which, despite perhaps presenting a positive financial return, lack long-term social and environmental results, since the negative externality is public and not calculated in the pricing of these services. In March 2024, the Senate Plenary approved the National Circular Economy Policy (PNEC), authored by the Environment Commission, No. 1874 [16]. The law defines concepts, objectives and instruments of the PNEC that apply to the actions of civil society, public authorities and the business sector. It aims to break with the linear economic model of extraction–production–consumption–disposal and, at the same time, promote a fair and regenerative transition of ecosystems, conserving, adding or recovering the value of resources, materials and inputs in order to contribute to sustainable development. The National Confederation of Industries (CNI) recently launched a tool (see the Maturity Route tool for the circular economy, CNI, available at https://economiacircular.cni.com.br/, accessed on 14 May 2024) to help companies diagnose and map their respective degrees of maturity in terms of adapting to this new logic of integrated production of value chains and at each stage of the production life cycle of goods and services. PNEC envisages a new, integrated organization of production chains and each stage of the life cycles in the production of goods, services and products. This requires a reorganization of urban and regional planning, not only of SMGRS, but of the flows of materials, goods and services that permeate the urban space of cities and regions. Chapter III of the Law highlights in its Justification that "*[a]s long as it is profitable and easy to generate waste, there will be no change in behavior*", which notions considers that this entire

dynamic, complex and variable scenario in multiple dimensions is the context in which public managers must formulate their Integrated Solid Waste Management Plans in a still analogical manner, without compatible data and applied technology.

On the other hand, the National Digital Government Strategy (ENGD) Law No. 14,129, of 29 March 2021, establishes guidelines for Digital Government in Brazil, with objectives for the years 2024–2027. The general objective of the law seeks a more inclusive, effective, proactive, participatory and sustainable state, especially through the following points.

"I—offering solutions that meet the needs of society and recognize social inequalities and barriers to access to public services;

II—adapting its processes to the current demands of society, with innovation, adequate use of technologies, safe reuse of data and better application of public resources; and

III—transparency, access to information, social participation in the formulation of public policies and the promotion of sustainable development [17]."

In order to illustrate the integration of these three policies, we created a diagram using (as the diagram is large and difficult to read in the article format, we chose to leave a publicly accessible link, which is available at https://drive.google.com/file/d/1Hiy-ZE08XbUxPl53DbT_VQxPVDd-tNd0/view?usp=sharing, prepared by the author, accessed on 25 November 2024) the free ChatGPT 4 and Lucidchart versions with a prompt engineering developed by the author. In this diagram, we show, in a synthetic and summarized way, the complexity of stakeholders, agencies, actors, mechanisms, goals and objectives that a city must manage to comply with the legislation mentioned above. The diagram aims to present the complexity of planning and management to which the public sector is subjected to the interested public, considering the legal and regulatory context of the PNRS, PNEC and ENG.

Our main objective in this article is to answer the following gap in the literature: how can we digitally transform this complex sectoral policy for urban solid waste management for a zero-waste and circular future for cities? Given that our hypothesis is that, once supported by a digital government structure focused on the conception of zero-waste cities and a circular economy, this policy (if well-conducted and well-implemented) can trigger a process of systemic and disruptive innovation. In other words, it can change products, processes, organizational, communication and marketing forms, and end up replacing the value chain of the linear economy with the formatting of a value chain based on the concept of the zero-waste and circular economy.

1.2. Digital Policies and Innovation Impact for Cities

The concept of systemic and disruptive innovation has been gaining ground in scientific discussion as a key element for the sustainable transition of organizations, cities, regions and territories. We are promoting the idea that digitalizing the sector through a digital government platform for zero-waste cities and a circular economy can support and accelerate this process. This need, for a new policy represented by a new set of programs, projects, actions and organizations, constitutes precisely an intrinsic need for systemic and disruptive innovation to establish the generation of shared value while reducing the entropy of the system, promoting and directing sustainable territorial development based on the reorganization of urban solid-waste value chains through municipal innovation processes.

This problem demands a serious discussion of a state policy that seeks, through innovation, to support the solution and transition to a real sustainable development model. The Brazilian State, through the Union, shows progress by enacting the new Innovation Public Procurement Law, precisely with the objective of helping federated entities and direct and indirect public administration to solve complex urban problems (on this issue, see the material from the Federal Court of Auditors on the Innovation Public Procurement Day,

which allows Brazilian municipalities to purchase technology and innovation to help solve complex urban problems, available at https://portal.tcu.gov.br/transparencia-e-prestacao-de-contas/servico/encomendas-tecnologicas-etec, accessed on 15 December 2023).

We discuss how technologies based on webGIS geographic information systems can serve as an online tool to support this transformation process if they are adopted by agents promoting macro-processes of systemic innovation such as government, states and innovation development agencies, serving as the basis for a digital government and corroborating the National Digital Government Strategy 2024–2027 (see Brazil's National Digital Government Strategy at www.gov.br, accessed on 7 April 2024), which aims to carry out the digital transformation of public services, improving efficiency, accessibility and the positive impact of government services on Brazilian society.

This article is structured as follows. In Section 2, we present the methodology from which we structured our article and concepts, starting from the social sciences and the concept of sustainability science, and an exploratory bibliographic review on the central concepts as the basis of the proposed approach. In Section 3, Results and Discussion, we present the main findings on the State of the Art of the central concepts of the research, presenting a dense theoretical framework on the proposed concepts and the need for their joint articulation to address the issues addressed. The reader is also presented with the initial conception of the digital government structure and the results of the interaction with local government through the promotion of this vision and development perspective. Finally, in Section 4, Discussion, we delve deeper into the analysis of the results presented, that is, the difficulties encountered in the practical and research fields to overcome current challenges and corroborate the transition of cities to the circular economy and zero-waste model. Future themes of study and approaches unfold with the presentation of this research article.

This article presents the initial results of ongoing research. The problem and central objective of the research is to propose an initial digital government structure for cities that can be used to change the paradigm of urban solid waste planning and management, an area that remains a research gap in cities and even for control bodies. How to develop and initiate a systemic and disruptive innovation program in cities to change the waste management paradigm? How to propose a digital government tool for cities that serves as support for the zero-waste and circular economy municipal innovation program? These are questions that motivate our science and applied research to solve complex urban problems in favor of sustainable development and the UN SDGs.

2. Theoretical and Methodological Framework

Thinking about innovative public policies as a driver for the sustainable development of cities and regions requires a science of sustainability, which is, at the same time, academic and social, trans and interdisciplinary, uncertain and exploratory, as it underlies [18] and constitutes the background methodology from which we build our logic to answer the central research questions. Other concepts such as cyberspace [19], network society [20], organization of collective intelligence [21], e-gov [22] transformation and digital government [23] permeate the text as they support the discussion and formulation of the proposed approach. In other words, it bases the methodology of theoretical-practical interpretation on the global problem, which finds in cities and local administrations, its microscale as a locus of ontological manifestation of the phenomenon and organizational unit of management, planning and immediate response to the phenomenon.

In the city dimension, at its local scale, the multipurpose territorial registry (CTM) has demonstrated its effectiveness in planning, ordering and territorial and city management [24]. Territory management begins with the recognition of the anthropized territorial

portion. The aggregation of information about the same territorial parcel is one of the objectives of the CTM. This way, we are able to connect data to their own spatialities and the territory and assign responsibilities to occupants and agents of these territorial parcels. Geographic information systems are the unfolding of this methodological application. The webGIS online geographic information systems digitize this scientific methodology for planning urban space and managing cities. It is precisely this logic of geographic information systems that supports our digital government structure, especially when we look at the PMGIRS diagram and recognize the enormous complexity that municipalities have to face in order to plan and manage a sectoral public policy aimed at the development of the circular economy and zero-waste cities.

In that regard, an exploratory literature review of three key concepts that interrelate in our approach was conducted, namely zero-waste cities, webGIS (with application in waste and smart waste) and disruptive innovation.

Figure 1 represents the methodology we followed to conduct this exploratory bibliographic analysis regarding the State of the Art about the three fundamental concepts presented. These concepts are interrelated and connected since a zero-waste city generates a quantum of disruptive innovation in the logic of planning, organization and management of the entire waste-value chain, its processes, infrastructures and multiple stakeholders. WebGIS is the conceptual basis supporting a digital government structure. Thus, for the proposed macroscale analysis methodology, we carried out an exploratory bibliographic review, searching for all types of publications that presented the words "zero waste", "systemic innovation" and "webGIS" in exact correspondence in the study title, but in three different searches. As we intend to analyze the global application of the concepts, we chose to seek to aggregate scientific productions segregated by continents, especially with regard to publications on zero-waste strategies for cities. We established a range between 15 and 30 publications per keyword that make up the central axis of analysis for the article. The objective is to bring the State of the Art of scientific and legal productions as well as experience reports among other types of publications related to the proposed key words. We chose the *Dimension* (platform available on the website https://www.dimensions.ai, accessed on 15 September 2023) search platform because, with more than 1.8 billion publications, it is one of the most complete platforms today and it can be accessed by anyone. The part of the results presented as the beginning of the initial concepts of digital government, webGIS platform for managing zero-waste cities and circular economy, emerged from the author's empirical work with the host city, who applied the concepts and logic of development based on the technology of webGIS platforms and digitization and digital transformation of public policies.

Figure 1 represents the framework adopted as part of the first part of the research. The first part of the research consists of this exploratory survey of the State of the Art of fundamental concepts for our general objective and research questions and its propositional articulation at the local scale of the city, in which we promote this approach with public agents of the local government.

Our methodology in a first dimension is based on the methodology of sustainability science to support long-term sustainable development through innovative public policies (circular economy and zero-waste city) and is based on theories and operational concepts of cyberspace, organization of collective intelligence, network society, multipurpose territorial registry, the local scale, digital government and the legal and normative framework itself on the issue to support the proposition of the vision and means of implementation within the scope of local governments through the case study proposed and promoted by the author.

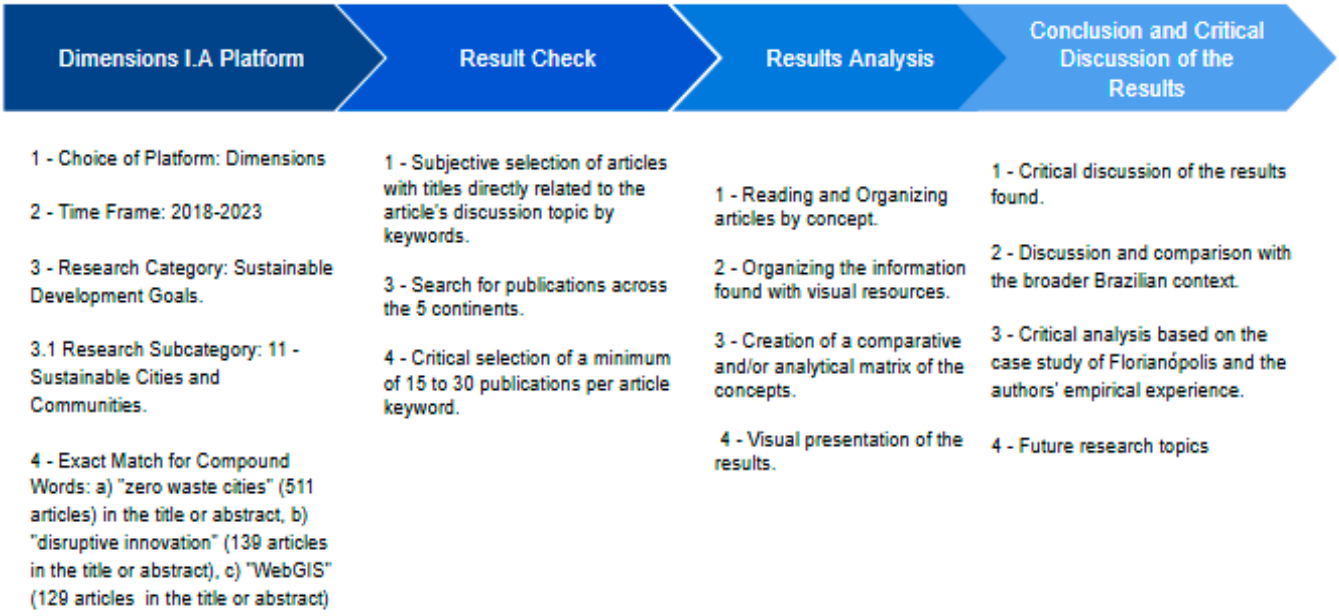

Figure 1. Exploratory literature review methodology of the three central concepts of the research. Created by author.

Our exploratory bibliographic methodology, as described in Figure 1, aims to demonstrate the State of the Art of how different cities and regions are implementing the concept of zero-waste cities and its implications, which corroborates the proposed vision of this socio-environmental and economic territorial development. It aims to demonstrate how disruptive innovation processes can be fostered and used to transition from obsolete socio-technical systems, such as the linear economy, in our view. The State of the Art of applications of the webGIS concept to the management, handling and governance of solid waste underpins this methodology, serving as a central point to support the proposal of a digital government structure for the implementation of zero-waste cities.

It is the articulation between these two theoretical–methodological dimensions that allowed us to present the idea of zero-waste cities as a possible global perspective for resilience to climate change. It was articulated to support the adoption of the logic of webGIS as a fundamental methodology for the management and territorial planning of complex public policies that can perhaps only achieve success through an innovative process. It also proposes, as seen in Figures 2–4, a practical application in the proposed case study, namely a materialization of these theoretical–methodological principles. It is through the idea of cyberspace represented in Figure 2 that we are able to virtualize entities, people, organizations, infrastructures and processes in order to update them and shift their territorialities that, when virtualized, allow them to be updated with new business and behavior rules, corroborating the organization of the collective intelligence of the local territory of the city through a strategic agenda for the implementation of a zero-waste city. The adoption, promotion and induction of this structure, from the perspective of an E-Government, that is, the state itself, can (and should) trigger a process of disruptive innovation that, in the long term, (as a public policy for sustainable development), will end up replacing the previous value chain represented by the logic of the linear economy.

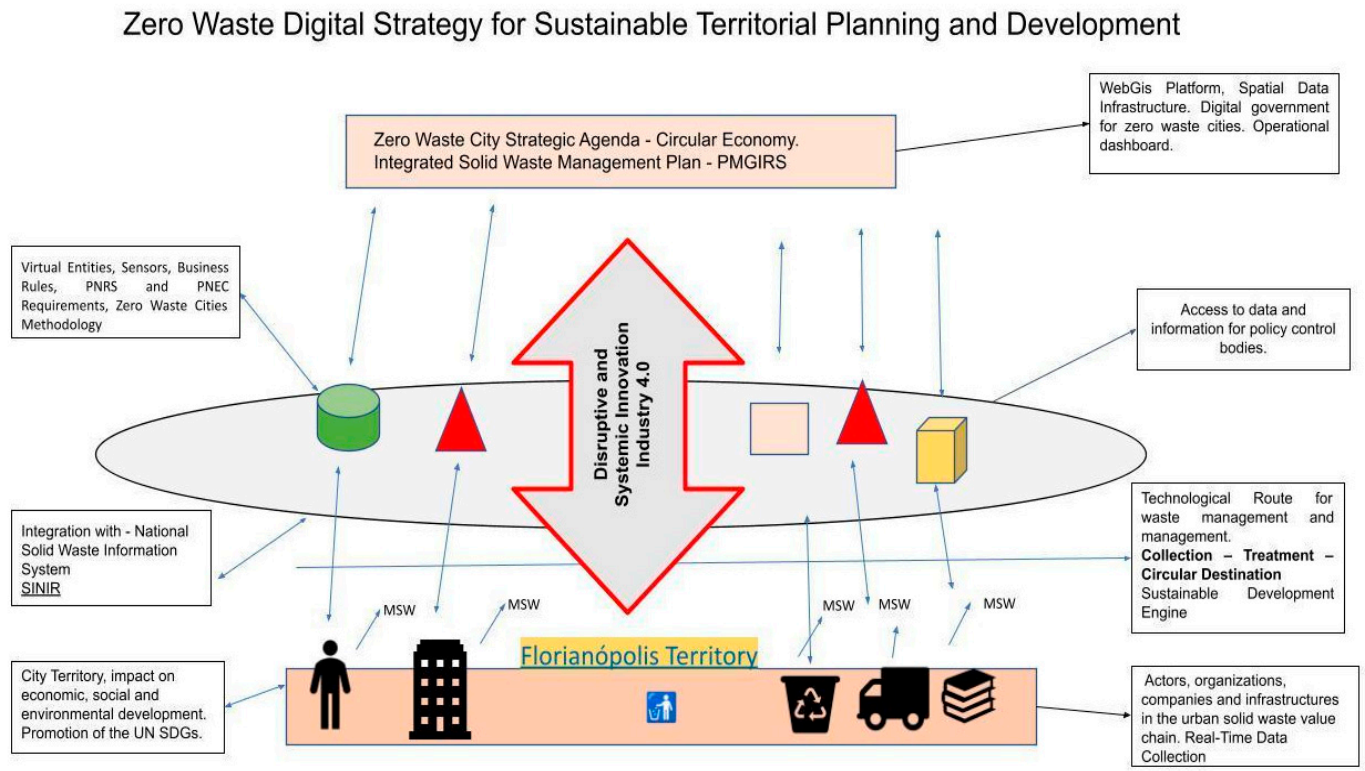

Figure 2. Initial conception of value chain virtualization. Prepared by the Author.

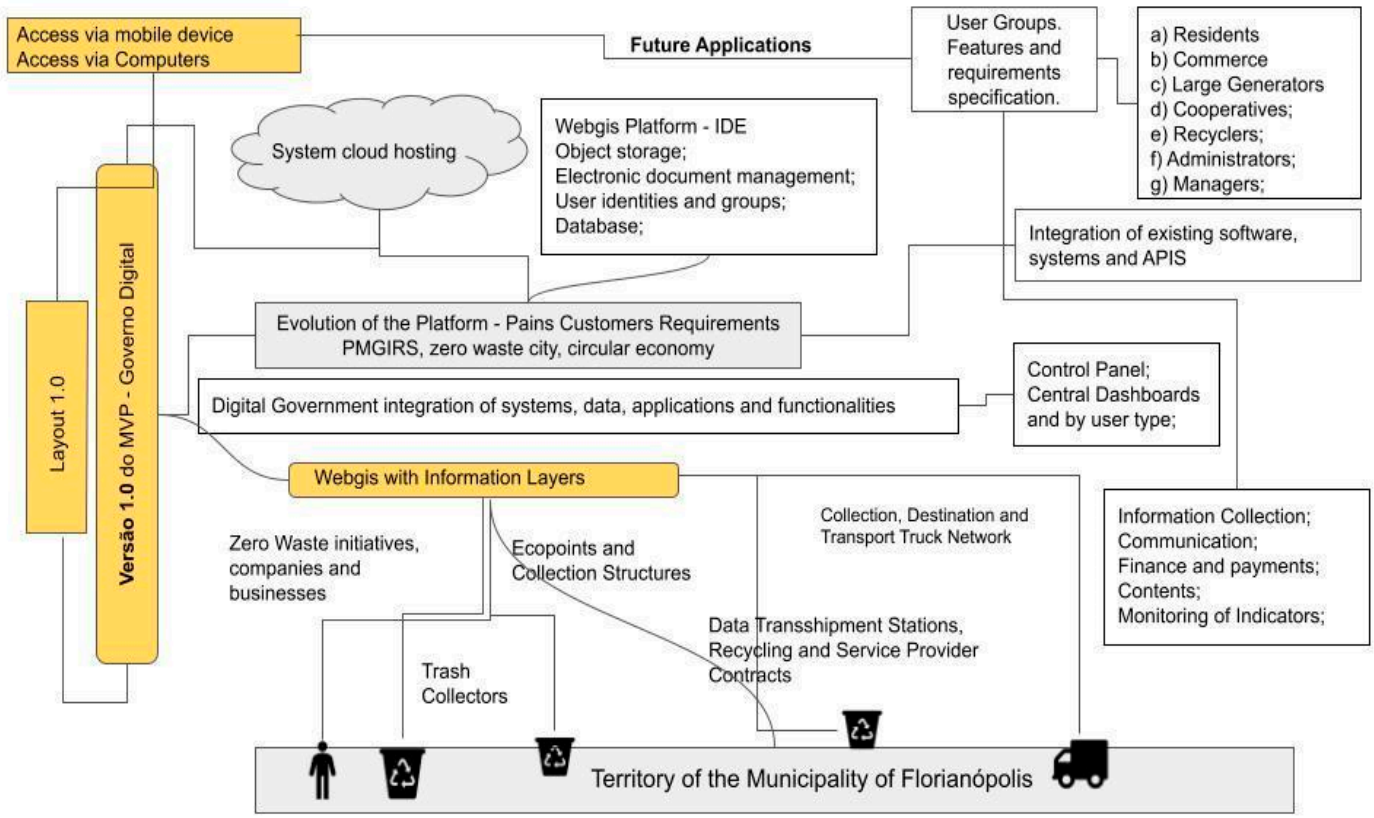

Figure 3. Initial design of the digital government structure. Prepared by the Author.

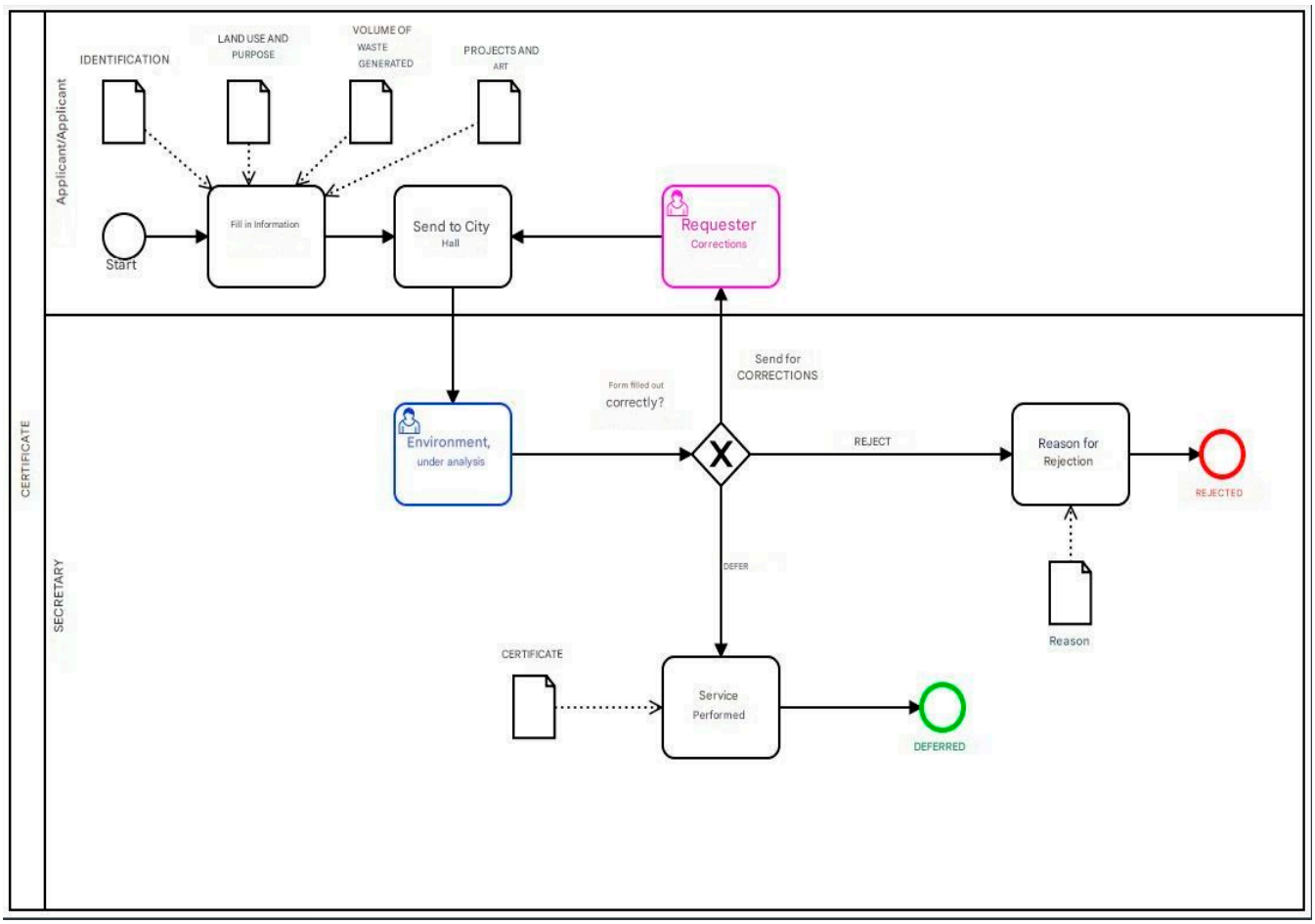

Figure 4. Digitization of the public service for initiating collection requests for new generator units. Prepared by the Author.

3. Results and Discussions

The objective of this section is to present the main results found in our study. Firstly, the exploratory bibliographic review, and secondly, the practical results of our vision and the application of this vision with the local government, as represented by Figures 2–4, are presented.

3.1. Zero-Waste Cities, a Global Perspective on Sustainable Resilience?

Zero-waste cities have been the subject of growing bibliographical production around the world, with productions focusing on building zero-waste cities, private initiatives and the general public. However, the notion of a circular economy can be a factor in win–win relationships to support metal flows in a more balanced way between nations, countries and regions, given that the amount of elements in the cosmos is constant while natural resources are finite [25,26].

Countries like China have used the zero-waste strategy as a way to combat climate change, making it a national policy that must be adopted by all cities in the country. Reaching all stages of the production system, from the extraction of raw materials to the manufacture of rockets, the strategy is presented as a guideline from the Chinese central government, which modifies part of the industrial metabolism into an eco-industrial one with public recognition of good initiatives, government regulation and perception of cost reduction and negative externalities in the territory. Studies even point to a 40% reduction in greenhouse gas emissions in cities across the country. A national evaluation method that can be applied to all cities (more than 100) in the country is currently one of the

central debates in the country, as a way of evaluating the efficiency and effectiveness of the implementation of municipal zero-waste city programs. The first systems of evaluation indicators and digital waste management systems have emerged in the country in economic chains based on coal resources. An intelligent construction waste management platform, through GIS remote monitoring, IOT significantly increased the recovery rate of these materials [26–33].

When analyzing the benefits of the method of sending zero resources to the landfill in Boston, that is, using waste combustion to produce electrical energy (WtE), the increase in renewable energy sources will make the technological route inefficient in reducing GHG [34]. Considering the recycling saturation rate in cities such as Tokyo, London, Singapore, etc., the New York health department used reuse and reduction strategies (clothes, goods and equipment, for example) as a way to increase the diversion of materials to landfill, creating a platform that calculates the impact of reuse on the city [35]. US state and local governments can increase the rate of landfill diversion by implementing anaerobic digestion in the organic fraction of city waste and accelerate the implementation of the zero-waste strategy, generating co-products such as biogas, fertilizers and compounds [36]. Organic waste is a source of fertilizers such as nitrogen (N) for sustainable agricultural systems guided by a new circular economy, as demand for (N) and fertilizers are central issues for human safety and health [37].

Efficiency in the provision of waste handling and management services is a central issue in the discussion, as it directly impacts the tariff for the service provided. Population size, demographic density, per capita income and operational environment are central in the analysis, in parallel with the adoption of the zero-waste strategy by local governments, along with the model and form of provision of public services, whether municipal, private or mixed. Of the 279 municipalities in the Tuscany region, Italy, 11 are municipal, 125 are public–private and 18 are completely private. No superior management model or privatization is being highlighted, suggesting that the formal commitment of local governments in the region to the strategy results in greater efficiency and positive public service orientation [38].

Far from extinguishing the State of the Art, the results support the vision of a categorical imperative for the world's cities from the perspective of urban sustainability, public policy, and the country's national and local economy, as it can boost goods and services in a wave of innovation, in greater symbiosis with cities, where flows of matter leaving cities after consumption and use become *inputs* for new production processes of goods and services.

3.2. WebGIS, Digital Government and Disruptive Innovation

Processes of systemic and disruptive innovation in obsolete socio-technical systems are concepts that we evoke as subsidies to promote the transition from the linear economy to the circular economy, especially using the zero-waste cities methodology. Systemic innovation here means a change in process methods, organization, marketing and/or products and services, while disruptive innovation replaces a value chain with a completely new one. Disruptive technologies that can be applied to the concept of smart cities are listed as follows: information and science, materials, energy, manufacturing, transport and pioneering technologies that can change the way consumers, businesses and industries operate in their territories, contributing to sustainable development [39]. New urban mobility businesses, based on the shared economy, are responsible for the sustainable co-evolution of city territories in Asia, while enabling the accumulation of social capital (social connection, shared trust and understanding of urban communities) and the ecosystem innovation business towards greener and smarter urban transport [40,41].

The concept of a zero-waste city with maximum waste recovery and the elimination of landfilling and/or burning of resources, translated into a public policy program, finds its means of support and implementation (mobilization, coordination, evaluation) in this digital government structure whose implementation is and should result in a process of disruptive innovation fostered by the local government itself (which replaces the established processes of the linear economy) and opens up horizons for sustainable development. The impact of digitalization on waste handling and management and on the circular economy is enormous. The digitalization of the sector, in addition to increasing the volume of recovered resources, can save between 30% and 35% of municipal public budgets allocated to this public policy, representing around 493 billion dollars by 2030, with a predictable reduction of 15% in total CO_2 emissions by 2030 [42]. The interaction between industry and the environment is crucial to the performance of Norway's own industries. The idea of industrial symbiosis consists of the *outputs* of one industry and *inputs* for others, encouraging the formation of eco-industrial parks, which enable and allow the shared use of infrastructure, energy and material flows, supporting the construction of zero-waste cities and a circular economy [43]. The informal city hides informal infrastructures that can impact urban planning and the development of public policies. These are new paths for citizen autonomy, allowing us to understand the informal city as a place of innovation and continuous learning, as demonstrated by mini solar energy generation networks in Cape Town [44].

To address the challenges faced by scientists and managers working in the area of urban waste management, ref. [45] analyzed the State of the Art in the combination of remote sensing, geographic information systems (GIS) and various tools and techniques such as multicriteria analysis, fuzzy logic, data analysis, geotags, georeferencing, etc., to highlight how this set of principles, techniques, methods, and tools are helping scientists and the waste management sector in challenges ranging from extraction to proper final disposal, including the shared responsibility of each generator, the choice of location of transfer stations, route optimization and clue-based analysis for better resource recovery. All these areas and dimensions of the waste management value chain can benefit from the combination of these techniques, principles, and methods.

Urban waste management logistics is a logistical subsystem that constitutes part of the functioning of a smart city, a new conceptual structure for smart cities, means using interdisciplinary approaches, disruptive innovations in order to increase the quality of services provided to citizens, including logistical systems, door-to-door and reverse logistics systems. These are fundamental components of waste management [46]. Both a culture of disruptive thinking and the exploration of human and social potential are themes for future research and an indispensable component of the SDGs [47], in parallel with the use of artificial intelligence (AI) still being a recent field of study in the context of smart cities, with limits to the impacts and risks of using these technologies on a large scale in cities [48].

Emerging technologies such as blockchain, internet of things (IOT), ICT information technologies and digital governments can bring citizens closer to smart cities, since such technologies change the way citizens interact with the city and local governments [49]. In this way, the precarious conditions of municipal "garbage" collection systems in India can be overcome with the use of intelligent digital platforms, IOT, remote sensing and modern management dashboards [50]. *Garbage Zero*, a research project funded by the Ministry of Electronics and Information Technology of India, aims to develop solutions based on IOT optimizing routes and low energy consumption strategies, using modulated sensors installed in public waste containers in order to generate real-time data [51].

The concept of webGIS has been used to help solve complex urban problems, encouraging the scale of participation in urban planning across different groups of stakeholders in the

city, enabling the proposition of projects and subprojects across the city [52], in addition to enabling geolocation of data collection and capture structures such as temperature, gasses, ideal location and optimization of waste-handling and waste management systems [53]. Urban environmental governance and the appearance of the city have been issues in which webGIS systems have presented effective results in data analysis for decision-makers and public managers [26]. The city of Kumming in China found the use of webGIS to be an important tool for supporting, maintaining and managing the city's urban drainage and sanitation, fundamental to the population's quality of life [54].

Such uses and implementations indicate that new urbanism, urban planning and development are undergoing a new formulation and restructuring, given the rapid urban expansion across the globe. The integration between the BIM construction information system and geographic information systems (GIS), H—dimensional—refers to the incorporation of time in webGIS for even more robust analysis, configuring key elements in the restructuring of urban planning and development.

In our scientific and research journey, we had several interactions with and made proposals to local governments, especially in the city of Florianopolis, with the aim of carrying out technical–scientific cooperation with the aim of enabling and supporting the process of building a zero-waste city from development of a digital tool that constitutes a first-order problem in all cities in Brazil, since the entire planning and management process of PMGIRS and waste handling and management are still in the analog state, not meeting the challenges, goals and objectives proposed by the Brazilian guidelines and national laws.

Figure 2 represents the initial conception of the development of the webGIS platform and the Digital Government. It is part of the logic of virtualization of the entire urban solid-waste value chain, including all types of generators, companies, organizations, infrastructures and actors with legal responsibility, and it is linked to the PMGIRS of each city. It uses the webGIS principle to expand data collection, control, participation and *accountability* in this sectoral public policy for innovation and paradigm shift towards zero waste and a circular economy. Virtualized entities are converted into virtual entities where they must respond to requirements and business rules in accordance with their ideal role in the system. The infrastructures are remotely sensed, such as collection trucks, containers, and sorting and recycling stations.

Figure 3 represents the subsequent development diagram of the initial conception, sketching a first relational infrastructure of entities, infrastructures, layouts, users and relationships between the parties that establish the operating logic of the system designed to manage a zero-waste city with a circular economy. The generation of big data on the solid-waste value chain, the mapping of material flows, the optimization and digitization of public services and the digitization of documents are prerogatives for the functioning of a digital government structure that supports the transition to a zero-waste city with a circular economy.

Figure 4 represents the digitalization of one of the public services in the city of Florianópolis, developed during a technical and scientific cooperation agreement with the author. The flow in question is a requirement from the city hall to begin collecting solid household waste in new units. A process, once analog, was completely digitalized to facilitate and give efficiency and effectiveness to this digital service that could be performed by any computer connected to the internet. The flow requires the delivery of the identification of the real estate unit, (linking the unit to the CTM Multipurpose Territorial Registry), the purpose of land use and occupation, the volume of waste generated by the unit, applicable projects and certificates of technical responsibility. After collection, the process is sent to an analyst from the city's environmental department, who will check compliance and non-conformity, granting the request, sending it back for corrections and/or rejecting the

request. The entire procedural process can be monitored by the applicant, analyst and manager of the responsible secretariat, forming one of the services that make up the IDE spatial data structure and digital government for zero-waste cities and a circular economy. It represents innovation and the digital transformation of the public sector linked to waste, or at least the beginning of this process.

4. Discussion

The exploratory bibliographical survey of the State of the Art on zero-waste cities demonstrated that, in addition to the topic having gained a volume of scientific publications from 2018 to 2023, several countries have been adopting the methodology and concept as a state policy guideline in waste management. China stood out as the most advanced country on the subject, following a guideline from the Chinese Communist Party (PCC). The country has been adopting the concept simultaneously in more than 100 cities, applying the methodology in different segments of the industry, covering areas such as mining, civil construction, and production of goods and services, such as the production of rockets with recyclable modules, demonstrating that the zero-waste and circular economy strategy is an important geopolitical factor for the development of countries, cities and regions. One of the difficulties encountered is precisely a national system that serves the country's central government as a tool for analyzing the implementation of municipal and regional programs for zero-waste cities, which is in line with our proposal and research scope. In addition to proving to be an important tool in the fight against and resilience to climate change, the sector is responsible for large GHG emissions. The adoption of the zero-waste and circular economy concept, associated with digitalization, can lead to a reduction in operational costs and general GHG emissions, demonstrating a potential of 15% to 40% in reducing emissions, and saving around USD 493 billion by 2030 [32,42]

The digitalization of the civil construction waste-value chain, in China, proved to be effective in increasing the recovery rate of these materials from landfill by using geotechnologies, webGIS and IOT to support the regulation, implementation and development of public policies. Boston, which adopted the WtE model as a way of "eliminating" these resources and generating electrical energy, demonstrates that the system does not enjoy long-term sustainability, since the diversification of renewable energy sources tends to decline, while the scarcity of natural resources and commodities rise, as well as the operational costs of management and collection systems, which, in the case of a WtE plan, are usually centralized systems. Cities that found their recycling rates saturated at around 60% used reuse strategies and reduction in waste generation as complementary strategies to combat uncontrolled waste generation. New York City launched a platform to encourage, facilitate and encourage the adoption of reuse as a strategy in the fight against zero waste. Anaerobic Digestion is another strategy that can be used to massively reduce the sending of organic waste to landfill, in addition to generating products and by-products that can serve as inputs and impact the reduction in operational costs in the agricultural sector close to cities. The Tuscany region in Italy demonstrated that, even though there was no superior management model (public, public–private, private), the public authorities' commitment to the zero-waste strategy was what best generated positive results for the cities.

The idea of presenting a proposal for a digital government for zero-waste cities based on webGIS was fulfilled by the article. Both the introduction to the topic, the Brazilian legal context and the theoretical–methodological framework corroborate to support the argument that perhaps a digital government structure, adopted by the local entity, as an innovative and disruptive way of transforming the management and development model of municipal waste systems into a zero-waste system, is supported.

The greatest difficulty in evaluating the proposed model lies in articulating the concept (zero-waste city) in the local government dimension, since it requires the agreement of results and the convincing of executive managers, such as mayors, secretaries, control bodies and/or departments with the capacity to mobilize, articulate and implement sectoral public policies. In our case study, we did this initially by seeking to raise awareness among managers about the problem and its solutions, arguing about the perspective of innovation and its benefits in generating value for all stakeholders in the process. Another obstacle is the difficulty in having civil servants, managers and employees trained in the concept of zero-waste cities and a circular economy, understand, use and design the logic of webGIS systems to facilitate the work routine and planning, as well as the near-total absence of management and planning tools for this sectoral public policy.

5. Conclusions and Further Work

Conceiving territorial planning today in an analogical way, as a form of resilience to extreme climate events and sustainable territorial development sounds like a bad joke. The digitalization of public policies and the digital transformation of governments change the way citizens interact with governments, the city and the effective impact that sectoral public policies can have [49]. In this way, our conceptions and perception of the lack of adequate instruments for the planning and management of zero-waste cities and circular economies prove to be fruitful. The conception and development of the system evolved and found support in the city of Florianopolis, in the state of Santa Catarina, in southern Brazil, or at least from the city hall's technical and civil service team that supported the process of digital transformation of public services. It is worth noting that the state of Santa Catarina is experiencing an epidemic of illegality and corruption associated with contracts for the provision of services for the collection, management and transportation of urban solid waste. Between 2020 and 2024, 27 mayors were arrested, (see news about the facts at https://www.nsctotal.com.br/noticias/quem-sao-todos-os-prefeitos-presos-em-santa-catarina, accessed on 7 September 2024), approximately 10% of the mayors of the 295 municipalities. Furthermore, 89% of these municipalities are in legal non-compliance with the legal framework for basic sanitation, as reported by the State Court of Auditors (access the report at https://www.tcesc.tc.br/dados-sobre-gestao-de-residuos-solidos-nos-municipios-catarinenses-sao-apresentados-em-evento-no, accessed on 9 July 2024). The facts and circumstances that endorse our proposal for structuring a digital government for zero-waste cities are based on the role of the municipality whose state agent is the legal responsible and the holder of public services and who must follow the goals of the state of the union, regulate the provision of services, the control of polluting agents and waste generators, and articulate social and economic agents so that urban solid waste becomes an element of employment generation, income, and sustainable development. They must also articulate the private sector, civil society, and the public sector in support of these guidelines determined by the federal government of Brazil. The instruments, mechanisms, principles, goals and objectives of the PNRS, the PNEC and the national digital government strategy are already in place and awaiting implementation by federated entities and society in general. It represents an opportunity for innovation for the industry, the production of goods and services and society in general, but it requires an inducing agent (municipality and state) for this macro process of systemic and disruptive innovation, which can be promoted in the urban solid-waste value chain for the transition to the circular economy and zero-waste city model. In addition to reducing the amount of resources sent to landfills, the literature has shown that digitizing the sector can reduce the municipal budget allocated to this public policy by 30% to 35%. This is in addition to a reduction of around 15% in CO_2 emissions. A recent bidding contract (access the

report at https://saneamentobasico.com.br/florianopolis-inicia-licitacao-coleta/, accessed on 18 October 2024) for waste collection and management services in Florianópolis, in 2021, had an amount of approximately BRL 49.5 million for a period of 12 months. A 30% reduction in this amount represents a value of approximately BRL 14.850 million that could be saved in the municipality.

The vision of a zero-waste city with a circular economy implies the dependence of multiple stakeholders, ranging from the extractive industry, the manufacturing industry, research and development of new materials, molecules and structures, etc. It implies a strong institutional and regulatory cohesion over private and public agents that act in the production and consumption of goods and services.

In Brazil, access to resources and funds from the Federal Government, specifically for this purpose, the Federated States and Brazilian Cities, is conditioned on the existence of State Solid Waste Plans (PERS) and PMGIRS. All these plans must have principles, goals and objectives converging towards the circular economy and the vision of zero-waste cities, since these are the principles, goals and objectives that establish the PNRS and PNEC. Mechanisms such as Regenerative Finance and/or Sustainable Finance can be used by these state entities as initial capital for structuring these plans oriented towards this vision of sustainable development, since this adoption and implementation will return by reducing the local entropy of the system and its negative externalities, with lower operational costs for operators and society in general. Within the scope of the city and its administrative structure, the urgency of the phenomenon (removing garbage and waste from the streets) imposes an urgent agenda to solve the problem on the municipal public manager, with often few resources or a lack of management, control and accountability, over what is planned versus what is executed.

Despite the analog processes, the absence of reliable data and the lack of an integrated territorial planning capacity for this development vision, the articulation of this public policy and its digitalization encounters barriers ranging from the need for trained public servants to the lack of mobile devices for data collection in the field.

It is still necessary to calculate the economic impact that the continuation of this model has on cities and society. The trend of increasing the costs of the current collection and transfer systems, the saturation of landfill structures and their damage to landscapes must be added to the costs of lost opportunity due to these materials not being reinserted into the production chain with the retention or increase in their value throughout the life cycle. In addition, there are the environmental, economic and social benefits of the raw material that no longer needs to be extracted. The organic waste chain can generate fertilizers and manure for the surrounding agricultural systems, but it can also generate fuel gas to power collection and urban transport fleets. The construction waste chain can be used for new construction, maintenance, repairs and paving of the city itself. Both cities and companies—industries and services that require inputs of raw materials and/or resources to carry out their activities and generate value—can be enhanced by the organization of urban solid-waste value chains with the aim of reinserting, reusing, and recycling resources for new uses.

On the other hand, the implementation of this vision of integrated urban development requires qualified labor, financial resources to start new structures and public services structured to build this vision, as well as the capacity for planning, management and use of technologies that support this implementation. In a recent experience of technical–scientific cooperation with the local government for the digitalization of services, as demonstrated in Figure 4, it became evident that drivers and collection teams did not have smartphones or devices that allowed them to use the platform for the digitalization of the services and their work routine.

The exploratory review of the central concepts of the research demonstrates that although there are initiatives to digitize public services related to solid waste management, such as route optimizers and remote sensing of waste containers, no initiatives were found directly linked to the digitization of public policy associated with waste management, zero-waste cities or the circular economy. What we found was the digitization of specific chains, such as the construction waste chain in China, which drastically reduced the sending of these materials to landfills, in addition to helping regulate this public policy.

Below are some important points that we would like to highlight.

- Zero-waste cities are a growing trend among cities around the world.
- Geographic information systems on the web are robust methodologies that support a digital government structure, combine different technologies and integrate different entities and data.
- The digitalization of the waste management sector represents significant impacts in reducing operating costs, diverting resources from landfills and in the implementation of legal goals and objectives.
- The circular economy represents a horizon of sustainable development that can boost the economy of cities and regions.
- The state and local governments must induce disruptive innovation processes in the municipal solid-waste chain to accelerate the transition from obsolete socio-technical systems.
- The implementation of the concept of zero-waste cities, circular economy and the application of the proposed models encounter enormous difficulties in terms of the technical and scientific capacity of managers and public servants, lack of financing and integrated long-term planning.
- There is a lack of instruments and tools for planning and managing solid waste that respond to the Brazilian regulatory context, such as PNRS, PNEC and ENGD.
- The idea of a digital government structure to facilitate the transition of cities into zero-waste cities proves to be fruitful and applicable, and it opens horizons for new research and fields of study.

These are the results that we present and discuss at this first stage of our work, validating the real need of municipalities for digital transformation and the digitalization of this important municipal public policy. At this stage, we carried out the digitalization of some services related to municipal waste management, as demonstrated in the framework for requesting waste collection in new household units.

As the first stage of research, these are our preliminary results, with the objective of developing and designing the principles of a digital government structure for zero-waste cities and the circular economy in future stages.

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