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IoT-Based Framework for Connected Municipal Public Services in a Strategic Digital City Context

Danieli Aparecida From, Denis Alcides Rezende * and Donald Francisco Quintana Sequeira

Strategic Digital City Research Group, Pontifícia Universidade Católica do Paraná, Curitiba 80215-901, Brazil; danieli.from@pucpr.edu.br (D.A.F.); donald.francisco@pucpr.edu.br (D.F.Q.S.)
* Correspondence: denis.rezende@pucpr.br

Abstract: The use of digital technology resources in public services enhances efficiency, responsiveness, and citizens' quality of life through improved resource management, real-time monitoring, and service performance. The objective is to create and apply an IoT-based framework for connected municipal public services in a strategic digital city context. The research employed a modeling process validated in a Brazilian city, identifying seven related frameworks and four themes through a bibliometric review. The original framework comprises three constructs, eight subconstructs, and 12 variables, validated through a case study inquiry. The results revealed that the researched city has yet to enlarge IoT into its municipal public services as part of a digital city project initiative. Key recommendations for IoT implementation include prioritizing the preferences of digital citizens, expanding critical services suited for IoT, and updating municipal strategies to incorporate IT resources to streamline decision-making. The conclusion reiterates that the IoT framework for municipal services is effective when actionable information supports strategic planning and decision-making and highlights the transformative potential of IoT in driving more resilient and sustainable cities aligned with citizens' needs. This approach allows public managers to enhance citizens' quality of life while improving the efficiency and responsiveness of urban management processes and services.

Keywords: municipal public services; IoT connectivity; internet of things; information technology resources; strategic digital city; urban management

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1. Introduction

The United Nations Human Settlements Programme projects a rise in urban population from 54% to 66% by 2050 [1]. This demographic shift will affect urban planning, requiring the integration of the Internet of Things (IoT) into urban infrastructure, as it offers the potential to collect and transform data into valuable services for residents [2–4]. In Brazil, where 87% of the population resides in metropolitan areas, there is a pressing need to develop technological strategies that enhance the quality of life for urban inhabitants [5,6]. These strategies necessitate the implementation of precise information systems, information technology resources, and strategic methodologies for effective decision-making, supported by a municipal management model capable of addressing social challenges in a timely and strategic manner [7–10]. However, the current body of practical knowledge is not always socially and technologically appropriate in addressing the multifaceted complexities of urbanization, a situation further complicated by the inherent challenges associated with urban management and planning [11–14].

Information technology (IT) applications have enabled numerous connections between devices and individuals around the world, as well as the delivery of public services through

instant connectivity [15–17]. This phenomenon has led to a multitude of opportunities associated with the extensive network of interconnected devices, which currently exceeds 30 billion units [18–22]. For instance, studies discuss that digital public service design during the pandemic was contingent and emergent, requiring improvisation to ensure access amid government-imposed restrictions [23].

The research problems include the lack of digital inclusion policies, limited digital service provision, difficulties in accessing and navigating government websites, and bureaucratic hurdles [16,24,25]. Furthermore, in many cities, there is no established framework for fully integrating municipal public services through IoT, nor is there sufficient research on the impact of connected devices in government, including database security and cyberattack risks [26–28]. Moreover, it is pertinent to acknowledge that urban management encompasses social and technological multidimensional challenges such as energy infrastructure, sanitation, security, transportation, mobility, unemployment, and limited access to essential public services by users [12,29–31]. This underscores the State's and cities' inadequacy in fostering equitable and balanced urban management [18,32].

From the research problems described, the research question then arises about how to construct and analyze an original framework of municipal public services using IoT in a strategic digital city context, considering four subprojects (municipal strategies, municipal information, public services, and information technology resources).

Based on the research problems and the research question, the research objective is to create and apply an IoT-based framework for connected municipal public services in a strategic digital city context. The framework has constructs, subconstructs, and original variables that can be experienced in a city.

Regarding the strategic digital city context, the proposed framework is related to the four subprojects, and one of the information technology resources is the IoT itself and its respective technologies.

The research justifications are also rooted in the notion that public governance can encompass a digital policy structure, leading to a reduction in tax obligations on computers and associated equipment [28]. This is further complemented by equitable internet access that facilitates efficiency and responsiveness in delivering public services, also considering IoT resources [33,34]. Thus, the integration of IT by municipal governments fosters dynamic interaction between citizens and the city's local administration, thereby enabling improved access to public information and engendering greater transparency and reliability in public operations [9]. This, in turn, aids in encouraging digital political participation and respective strategies in the city [35].

The availability of public services, influenced by the ability to integrate and connect different objects, is emerging as a necessary and strategic resource for city management, enabling the delivery of customized services suitable for citizens [10,13]. Furthermore, studies conducted in urban areas have yielded favorable outcomes in terms of user experience of public services facilitated by IoT in comparison to those services that did not employ this resource [36].

In the same direction, a strategic digital city project undertakes the deployment of strategies, municipal information, and municipal public services through information technology, including IoT technological resources, in order to contribute to the effectiveness and cost reduction of public administration institutions [33,37,38]. In this journey, the expansion of this concept is acknowledged by incorporating citizens into the formulation of public policies, a process that can be facilitated by the utilization of IoT and municipal services design [31,39].

This research is original and novel because it proposes and demonstrates the utility, applicability, and feasibility of a municipal public services framework based on IoT technol-

ogy experienced within the strategic digital city context [21,32,38,40–42]. Also, it addresses existing gaps by proposing a novel framework for public services based on IoT technologies in strategic digital city subprojects. The proposed framework seeks to enhance municipal governance through the utilization of interconnected devices and data-driven decision-making processes, with the ultimate goal of improving service efficiency, accessibility, and security [43–45]. By integrating IoT technologies into public service management, this original framework offers a systematic approach to infrastructure optimization, reduction of administrative inefficiencies, and promotion of digital inclusion via user-centric service design [46,47]. Additionally, it presents a flexible and scalable model that can be adapted by municipalities to suit various urban environments, thereby facilitating a more resilient and sustainable approach to digital governance [48,49]. Other gaps also concern the lack of a framework such as the one proposed, which considers as a strategy the needs arising from the digital citizen himself, who is heard and welcomed so that the city can then plan public policies contemplating digital inclusion to improve the navigability and availability of digital public services [38,50].

The paper is made up of the following Sections: Section 1. Introduction, which essentially presents the research objective; Section 2. Literature Review and Background describe the concepts and approach that reference the research; Section 3. Materials and Methods report the research techniques, constructs, subconstructs, and variables, highlighting the original creation of the framework that is described in Section 4. IoT Framework and Results. Section 5. City Applicability and Discussion shows the framework application in a city, generating Section 6. Conclusion that summarizes the main research results.

2. Literature Review and Background

2.1. Connected Municipal Public Services

Connected municipal public services are all those provided directly to the population and take place in the city, i.e., in the local context, translating exclusive responsibility of the municipal public administration [51,52]. They are classified, named, and typified at the municipal level through information technology resources and can consider public motives, digital citizen preferences, and municipal governance [21,38].

Integrating information technology resources is critical in numerous definitions of connected municipal services [53,54]. Connected government, an alternative to Government 2.0, uses digital technologies to enhance citizen engagement, improve government efficiency, and facilitate real-time interactions between citizens and government [9,53]. This includes the use of mobile computing, the Internet of Things (IoT), social media, and Web 2.0 tools [31,53]. In the digital city and strategic digital city context, information technology resource platforms play a crucial role in the development of efficient services and municipal performance [38,55]. However, the implementation of information technology resources could present several barriers, including cybersecurity concerns and the digital divide [5,54,56]. The digital divide, particularly between urban and rural areas, constitutes a significant challenge to equitable access to connected municipal services [57]. Furthermore, the successful implementation of digital platforms necessitates careful consideration of cybersecurity architecture to ensure data confidentiality and service quality [13,54]. Local policymakers then have to articulate diverse visions based on specific territorial concerns and policy objectives, including improving service delivery, fostering economic development, and enhancing community connections [58–60], which can be considered digital city strategies [38,50,61].

2.1.1. Public Motives

A public motive is manifested when a digital citizen, or urban user, requests services from the local public administration, which evaluates this request based on the municipality's capacity, needs, and policies [62–64]. The public administration then considers whether this solicitation nature is political, as outlined in electoral promises, or technical, driven by necessity, chance, or emergency [21].

The public motives concept encompasses the diverse drivers behind individuals' and groups' actions and decisions within the public sphere [65,66]. Understanding these motives is crucial for effective policymaking, public administration, and social change [67]. The influence of managerial practices on public service delivery suggests that public motives are not solely intrinsic but can be shaped by organizational structures and public leadership styles, and three approaches to staff management (high performance, high commitment, and high involvement) are outlined as pertinent to understanding public service design and how managers impact citizen public service motivation [68]. In addition, empirical studies that include all dimensions of public service motivation to advance in this field suggest a predominant quantitative approach and methodology [69]. In contrast, a qualitative methodology utilizes in-depth interviews with experts to gather insights into socially responsible behavior [70]. Their findings reveal that such citizen behavior is influenced not only by economic and sociological factors but also by moral and ethical considerations. This empirical contrast highlights the complementary nature of quantitative and qualitative methods in studying public motives, with the necessity of a multifaceted approach employing diverse scopes to capture the complexity of human behavior and social contexts.

2.1.2. Digital Citizen Preferences

The concept of the digital citizen encompasses individuals who utilize digital technologies to interact with society, engage in civic activities, and access public services, thereby contributing to urban governance through electronic means [71,72]. Furthermore, digital citizens play a pivotal role in the implementation of e-services, collaborating from the inception of governmental entities' provision of opportunities to articulate and comprehend collective needs [73]. The preferences expressed by digital citizens serve as main concerns highlighting the public services that the community necessitates and expects from public administration entities' implementation [21,74].

There are several divisions in how researchers approach digital citizen preferences. Some studies focus on individual-level preferences, analyzing individual choices and behaviors in online environments to understand user preferences for digital privacy nudges [75,76]. Other studies emphasize collective preferences, exploring how shared values, social norms, and group dynamics shape online engagement and opinion formation [21,77]. This distinction is crucial, as individual choices can be influenced by collective dynamics, and understanding both is essential for a comprehensive management vision. Then, certain approaches prioritize economic efficiency, focusing on citizen preferences as primary determinants of social behavior [78]. Alternative perspectives consider broader social and political implications, analyzing the impact of digital technologies on democratic processes, information accessibility, and civic engagement [77,79]. The inadequacy of a solely economic approach in regulating digital markets for political information is emphasized by the necessity to consider factors beyond citizen preferences to ensure accurate information dissemination and diversity of opinion in public spheres [80].

2.1.3. Municipal Governance

Municipal governance is the ability of a government to articulate, provide services, and apply policies to design public services based on the experience of citizens from an innovative perspective, whether through working groups, workshops, public consultations, or interviews involving a virtual environment and citizen engagement [81,82]. On the other hand, in addition, public governance comprises the mechanisms established to develop a management culture guided by efficiency, quality, transparency, and accountability to citizen users [83–85]. In this way, municipal governance is composed of three mechanisms: leadership, strategy, and control, a concept that will be adopted for the research protocol to experiment with the original framework, with issues evaluated for each mechanism [86,87]:

- Leadership: people and skills; principles and behaviors; organizational leadership; governance system;
- Strategy: stakeholder relationships; organizational strategy; cross-organizational alignment;
- Control: risk management and internal control; internal audit; accountability and transparency.

The integration of technology, governance, and citizen participation are seen as key components for the success of urban planning initiatives, considering criteria such as privacy, security, and interoperability between different systems. As well as the critical processes of collecting and analyzing real-time data to improve urban systems and services in social affairs such as public transport, energy management, and healthcare [13,31,88].

Also, municipal governance, unlike the strategic digital city concept and model, has been driven by decentralization policies and technological advancements [89]. Essentially, municipal governance comprises the structures, processes, and mechanisms through which local governments manage resources, interact with stakeholders, and implement policies to foster sustainable urban development [48].

2.2. Internet of Things (IoT)

The Internet of Things or IoT is the term used to define a network of wirelessly connected objects or things that interact with and process information through sensors in a context of hyper-connectivity without relying on human intervention [27,90]. When the Internet of Things concept was first presented, it described how the Internet would reach a stage where ubiquitous sensors would connect everything through interoperable objects identified solely by radio frequency identification (RFID) technology [91]. However, the precise conceptualization of the IoT is still being shaped [92,93]. The words 'Internet' and 'things' were put together to represent an interconnected global network based on sensing, communication, networking, and information processing technologies, which could be the updated version of information technology (IT) resources [94–96].

2.2.1. Connected Objects

The IoT can be conceptualized as a network of interconnected physical objects equipped with sensors that facilitate interaction, creating a pervasive computing ecosystem [95,97]. This ecosystem has the potential to significantly enhance people's daily lives, as evidenced by the emergence of several applications, including personal health monitors, smart appliances, humidity and temperature sensors, human behavior analysis, and autonomous transport systems [18,88,98,99]. The opportunities are boundless, and the quality of life can be effectively enhanced, as it reduces the effort required for humans to complete tasks of minor importance [100]. In addition, IoT is not a singular technology but rather a confluence of technological advancements in the information technology domain [21].

Scientific production on the specific use of IoT in healthcare has been growing since 2010 [101]. The countries that publish the most articles on this subject are the USA, China, and Germany, with a focus on the use of sensors for patient monitoring, wearables, wireless

sensor networks, and voice recognition technologies for healthcare [88,96]. A model of the contextual dynamics of IoT in public services states that for a public service to innovate [21], the following must be considered: public motives, which is a contextual factor to be considered for public services that use IoT as an innovation item. In other words, it represents a new solution in favor of the public good, as this differentiates it from market logic [71].

The implementation of a novel solution is susceptible to variation in characteristics, contingent on the geographical location to which the service is to be delivered. Furthermore, user preferences have been identified as a significant factor in the evolution of public service design [67]. These preferences encompass a range of factors, including device preferences, cognitive capacity, and the desire to access specific types of public services. Public managers then have the power to decide on new types of services to be offered, improve existing services, and advise on the formulation of public policies based on IoT technologies [21,87,102].

The IoT has received scant attention in the context of the public sector and governments, and there is a paucity of models for developing a structure or design for the provision of public services [29]. However, the IoT can facilitate easy access to a wide range of devices, including household appliances, monitoring cameras, displays, vehicles, and many other possibilities [103], leading to the development of novel methods for providing public services to citizens.

2.2.2. IoT-Based Cases in Municipal Public Services

Other case-based studies have shown the utility and feasibility of implementing IoT technology and principles in municipal public services, highlighting some areas of interest or performance dimensions:

a. Citizen-centric approach

Utilized network analysis to identify disparities in health service accessibility within the Calabria region of Italy [45]; research highlighted the significance of community-based urban development in fostering inclusivity and enhancing local service provision. The concept of Tech Justice [46] emphasizes equitable access to technology through a common-based governance approach. Their work advocated active citizen participation and co-management of urban technology, addressing social justice disparities in smart city initiatives.

b. Efficiency and sustainability enhancement

Implemented IoT-based fuzzy multi-agent systems within a smart city context for controlling smart street lighting; the implementation resulted in optimized energy utilization and a significant reduction in carbon emissions [44]. Furthermore, the systems demonstrated real-time adaptability to diverse urban environments.

c. Privacy and security concerns

Explored the application of multi-layered security measures and blockchain frameworks in smart cities [43] that provided real-world case insights into waste management and electronic voting systems, showcasing effective strategies to counter evolving cybersecurity threats. The integration of digital twins in e-government services [104] facilitated real-time data synchronization to optimize service delivery and citizen engagement while addressing concerns of privacy and efficiency.

d. Scalability and adaptability

Conducted a comparative analysis of low- and high-resolution infrared cameras for crowd monitoring in Nottingham, UK [105]; the findings indicated that while high-

resolution cameras exhibited superior accuracy, their costs posed challenges for large-scale implementation, underscoring the necessity for balanced IoT solutions. In a similar vein, ref. [106] examined the socio-economic impacts of flagship projects in Isfahan's Atigh Square, Iran; the findings indicated weak outcomes in the social and economic domains, underscoring the necessity for meticulous planning to align urban regeneration projects with the needs of the local community.

2.3. Strategic Digital City

The strategic digital city concept was originally created by Rezende to formalize a public policy model for the inclusion of citizens, not only technologically but mainly socially, considering the citizen's quality of life as a premise. Thus, all research on strategic digital cities explores whether a city meets specific urban criteria and adheres to parameters that define it as both digital and mainly strategic [38]. It also investigates how municipalities implement their information technology projects [107,108]. This inquiry aims to facilitate effective interaction and integration in the provision of public services based on IT, to raise awareness of the existence of these services, and to provide citizens with tools that enable interaction with public authorities in an agile way, as inclusive public policies [109,110]. An analysis of municipalities is adopted to ascertain the incorporation of communication, information, and access to information, as well as IT, within their municipal strategic planning and how they do so [111,112]. This is undertaken to develop strategic digital city projects and analyze the implementation of these in urban planning initiatives [50]. It is imperative to emphasize that the proposed strategic digital city conceptual framework could be studied, discussed, planned, and implemented from a top-down approach. However, it should be noted that, at the municipality's discretion, the model can be implemented partially or in a segmented manner but in a democratic, inclusive, and participatory manner with all the city's citizens and its public and private managers [38].

Digital city planning and IT, along with e-government and technological resources, can serve as complementary instruments for the effective management of cities, town halls, and municipal public organizations through timely and inclusive information and decisions [113,114]. Moreover, it can be acknowledged as a social approach within the public policy context, a notion substantiated by research initiatives [61] and publications in international scientific journals over the past decade. Then, the strategic digital city is comprised of four subprojects: municipal or city strategies (to achieve the municipality's objectives); municipal information (to assist citizens and municipal managers in decision-making); public services (to enhance citizens' quality of life); and applications of information technology resources. This social framework encompasses a comprehensive range of activities, extending far beyond the mere provision of internet access or digital inclusion policy. It involves the strategic utilization of information technology to manage municipal operations, with the overarching objective of enhancing the quality of life for citizens [38].

3. Materials and Methods

The action research started in March 2017 and was concluded in November 2024. The phases included bibliometric and systematic analysis of international literature from over 2000 raw academic articles in the Scopus and Web of Science databases [115,116]; analysis of models or frameworks and related themes [117,118]; and the construction of the original framework to be applied in one Brazilian city [119]. In the pursuit of the framework proposal, the methodology for knowledge construction was embedded in the theory of model building for the social sciences [120,121]. This approach ensures the applicability

of the model, whether developed within one or more Brazilian municipalities or in other countries, as a case study inquiry [122].

The research employed a mixed approach to identify state-of-the-art and research gaps in databases from 2019 to 2024, with an initial screening yielding 3294 raw articles [123,124]. From these, theoretical refinement is considered useful, resulting in 69 articles that support and confirm the originality and novelty of the framework. To strengthen the creation of the framework, each variable was made up of 4 columns (name of the variable; analysis question in the city; bibliographical references; and possible answers to be found in the city); thus, each of the selected articles was directly related to one or more research variables [122,125,126]. In the models, frameworks, and related themes investigation (predecessors or similar or related models), 7 correlated frameworks and 4 related themes were found involving IoT for the provision of public services. However, none of them considered digital citizens' needs and were not based on the concept and four subprojects of a strategic digital city, reiterating the originality of the proposed framework.

The data analysis also used examples of IoT application plans for Brazil and a 2017 National Bank for Economic and Social Development study as a referential parameter of public service IoT applications. The study then provides a comprehensive overview of the opportunities and challenges associated with IoT projects, with a particular focus on the potential impact of 'use cases' in diverse public environments and sectors [17,95]; then, it draws upon global values and estimates up to 2025, as reported by the McKinsey Global Institute.

Finally, the original structure was implemented in the city of São José dos Pinhais, in southern Brazil, as in-depth case study research [119,127], mainly because the city did not provide adequate public services through information technology resources, there was not enough capacity for integration and connectivity of objects that do not require human interaction to deliver personalized services, and there were no timely alternative solutions that IoT can offer [33,35]. It was also observed that during the execution of the action research, during 2023 and 2024, an IoT initiative was found that has become a reference for other cities: the "Muralha Digital" project, including an alternative for a citizen monitoring center, but it did not have all the resources that artificial intelligence allows to integrate with the city's public inspection, surveillance, and monitoring equipment. This subproject includes 421 high-tech cameras, highlighting the following public services: facial recognition, identification of car license plates, and integration with the civil and military police database, increasing citizen safety and reducing crime rates in the city (http://www.sjp.pr.gov.br (accessed on 19 November 2024)) [122].

A single case study was selected for this investigation because it enables in-depth, context-specific analysis, illustrating causal relationships and emerging patterns [119] [109]. Its methodological rigor, reinforced by structured qualitative approaches like thematic analysis, enhances theoretical contributions, and triangulating multiple data sources strengthens internal validity, making case studies a robust foundation for theory-building in complex phenomena [126,127].

From a diagrammatic point of view, the research process can be summarized as shown in Figure 1.

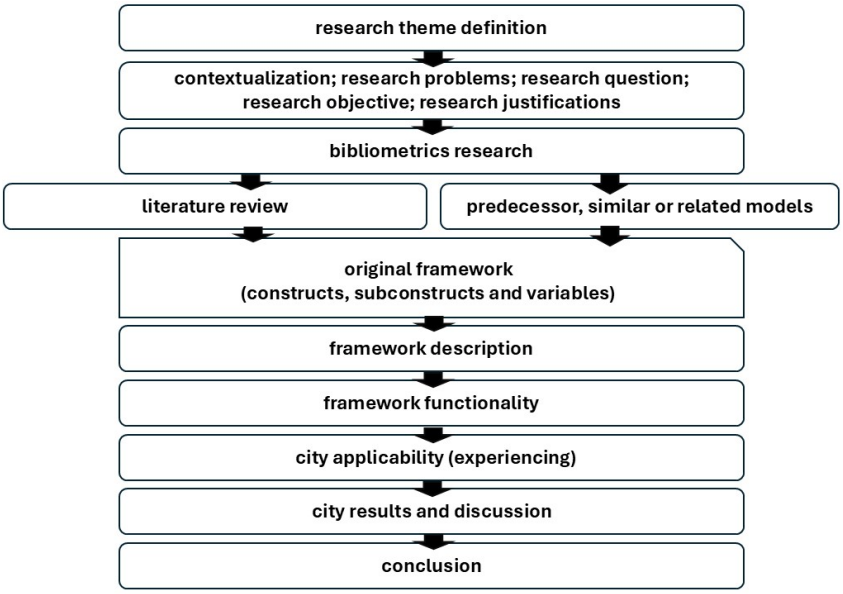

Figure 1. Research process.

4. IoT Framework and Results

4.1. Bibliometric Research Analysis

The research for models, frameworks, and related themes strengthened the building theory process since it can make it possible to analyze and compare eventual existing frameworks or models of municipal public services that involve the Internet of Things (IoT) in different contexts, assumptions, and variables. Thus, it was possible to reaffirm the originality and confirm Rezende's original concept that there are no frameworks or models for providing municipal public services connected through the IoT in a strategic digital city context [38].

Seven correlated frameworks (Table 1) and four related themes (Table 2) were found in the recent literature, which are worthy of consideration.

Table 1. Correlated frameworks and related themes.

Research Title	Year - Author
An integrated success model of Internet of Things (IoT)-based services in facilities management for the public sector	2022 - [16]
The contextual dynamics of Internet of Things applications in smart public bike sharing services	2017 - [21]
Internet of things for smart cities	2014 - [39]
Effectiveness of lifestyle intervention using the Internet of Things system for individuals with early type 2 diabetes mellitus	2020 - [88]
Business continuity management framework of Internet of Things (IoT)	2019 - [128]
Internet of Things: Applications and challenges in smart cities: a case study of IBM smart city projects	2016 - [129]
A web of things framework for restful applications and its experimentation in a smart city	2014 - [130]

Table 2. Related themes.

Research Title	Year - Author
A 5-step framework for measuring the quality of experience (QoE) of Internet of Things (IoT) services	2019 - [36]
An information framework for creating a smart city through the Internet of Things	2014 - [37]
Generation X and generation Y perception towards Internet of Things in public service: A preliminary study in Indonesia	2016 – [131]
Enabling smart cities through a cognitive management framework for the Internet of Things	2013 – [132]

4.2. Original Framework Construction

Then, the construction of the framework for municipal public services using the Internet of Things (IoT), considering the strategic digital city, demonstrates how the constructs and subconstructs relate to each other, thereby reinforcing the framework's originality and novelty. The original framework, represented by the model in Figure 2, posits a dynamic interrelationship between the constructs of connected municipal public services (subconstructs: public motives, digital citizen needs, and municipal governance), (2) Internet of Things (subconstruct: connected objects), and (3) strategic digital city, which is mediated by four subconstructs (municipal or city strategies, municipal information, municipal public services, and information technology resources).

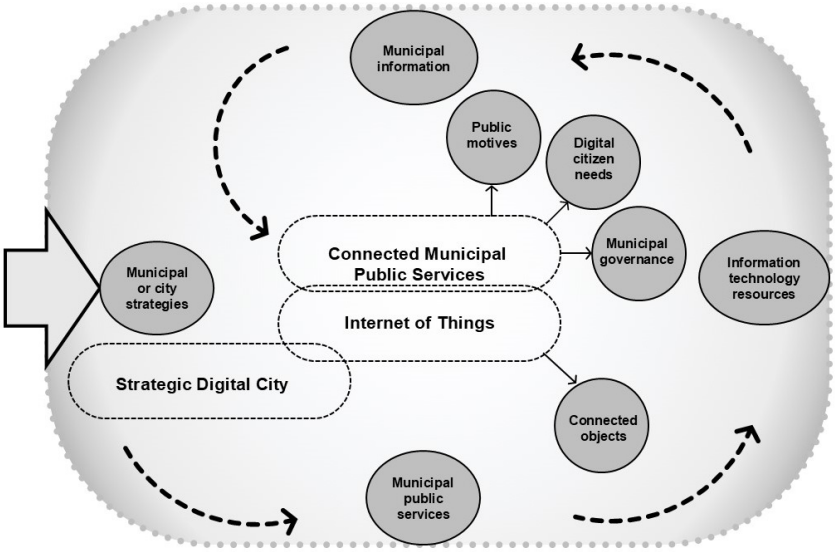

Figure 2. IoT-based framework for connected municipal public services in a strategic digital city context.

This logical reasoning is based on the premise that empirical observations and facts are theory-laden and can be interpreted through a conceptual framework containing inner mechanisms of functioning. This perspective is guided by the meanings ascribed to the constructs in the given context, taking into account analytical generalizations and methodological assumptions.

4.3. Framework Components Description

In the conceptualization of the "connected municipal public services construct", the term public services serves to denote the services provided by the municipality that can be delivered through the utilization of information technology resources. This construct is further delineated into three subconstructs: (1) public motives, which are the rationales

underlying the public manager's decision to provide a public service, informed by political criteria, such as those delineated in the government plans, technical criteria (extreme, fortuitous, or force majeure/disaster need) and/or legal criteria (obligation); (2) digital citizen needs, which are those preferences of digital users registering their needs on the online citizen service channel: software e-Sic, version 1. And finally, (3) municipal governance, which encompasses the public manager's decision regarding the provision of public service through IoT applications along with the necessary strategies to deliver those services.

The "IoT construct" encompasses all information technology resources employed to deliver connected municipal public service devices (e.g., sensors, smartphones, computers, mobile devices, and other objects), along with the subconstruct connected objects, which the latter refers to the types of objects utilizing IoT connectivity to provide a specific municipal public service.

The "strategic digital city construct" is comprised of municipal or city strategies, municipal information, municipal public services, and information technology resources that will facilitate the provision of connected municipal public services via IoT. It first encompasses the municipal or city strategies subconstruct, which comprises the strategies, projects, plans, programs, and actions necessary to implement the provision of municipal public services connected via IoT. The subconstruct municipal public services refers to public service demands in general, not exclusively those that can be facilitated through information technology resources and received via digital media. The subconstruct information technology resources are needed to enable the provision of connected municipal public services via the identified IoT. Finally, the municipal information subconstruct for citizens and public manager decision-making received via software e-Sic is also encompassed.

4.4. Framework Functionality

The framework is defined by the interdependence of its constituent elements: constructs, subconstructs, and variables. This collaborative operation is intended to address the needs of the digital citizen within the strategic digital city context, encompassing its municipal strategies, municipal information, public services, and information technology resources.

Once municipal information has been collected, specifically data on the provision of public service, municipal public management will be equipped with a list of public motives for formulating strategies capable of meeting the population's demand. This will allow the assessment of whether the service to be provided uses information technology resources and whether IoT can be considered an alternative to solving problems in terms of provision management of the public service. If such a scenario is deemed feasible, the service sought by the digital citizen will be facilitated through IoT connectivity, as delineated by this framework.

The municipal information flow is considered and observed through the official online channel for receiving citizen-users information in the municipal public administration, software e-Sic, since it is the only official means that provides more detailed reports and information on the São José dos Pinhais City Hall electronic portal. Consequently, the information received is utilized by the public manager to determine whether to operate an existing service through conventional channels or via IoT connectivity. This decision encompasses a decision-making process regarding the provision of a new service and the formulation of associated strategies, as well as the feasibility of incorporating IoT connectivity to address digital citizen needs.

Then, the strategic digital city project will give meaning to the connected municipal public services provided since the essential municipal information gathered by the digital citizens will give sense and content to strategy formulation, defining the types of public

services to be provided through information technology based on IoT connectivity, and what resources and objects suitable for application.

4.4.1. Connected Municipal Public Services Construct

(a) Public motives subconstruct

The connected municipal public services construct underscores the necessity to consider public motives subconstruct, given that, upon the identification of public requests, as frequently evidenced by citizen requests submitted via the software e-Sic platform, the context of the locality and the specific public service that must be evaluated to ascertain the potential benefits the requested service would bring to the community as a whole. The following concerns the variables involved:

- Name of the public motives: for the assessment of whether the public motives for the decision to offer or not a public service requested through the digital channel for receiving information by the municipal public administration were political, such as those provided in the government plan, technical (operational, municipal strategic planning, extreme necessity, fortuitous or force majeure/disaster), legal (obligation), among others.

(b) Digital citizen needs subconstruct

This subconstruct shows that the public manager will have to analyze the specific demands of digital citizens and, in the list of requests, identify which areas have the highest concentration of requests, i.e., which services are most frequently the targets of demand, and which result in service orders to be carried out by the municipal public administration. The following concerns the variables involved:

- The number of needs for municipal public services: the municipal public services requested via software e-Sic over twelve months should be assessed, and the volume in terms of citizen needs, i.e., which services are most frequently requested;
- Name of municipal public service needs: the names of the most requested public services by digital citizens via software e-Sic to be assessed;
- Name of the themes of municipal public service needs: the themes or municipal thematic involved in the most recurrent requests for municipal public services on software e-Sic should be assessed.

(c) Municipal governance subconstruct

This subconstruct highlights that the public manager, in possession of the information that enters through the municipal public administration, at the initiative of citizens, analyzes and decides whether this public service to be delivered can use IT and IoT at some stage of the strategy to be adopted, and from the point of view of leadership, strategy and control mechanisms because the public manager then will be establishing the governance in the municipality. The following concerns the variables involved:

- Name of municipal governance: this is where the possibilities of municipal governance with or without IoT (leadership, strategy, control) are to be assessed. This is the time to define whether or not the public service can be implemented and the mechanisms needed to implement the municipal public service with IoT, be they privacy, data security, control, or appropriate regulation for the use of the Internet of Things in the provision of municipal public services for the municipal public administration and citizens.

4.4.2. Internet of Things (IoT) Construct

(a) Connected objects subconstruct

This subconstruct can be regarded as the category of 'things' or objects that can be equipped with intelligent systems (e.g., sensors, smartphones, computers, mobile devices, among others) to facilitate the design of a connected public service through the performance potential of IoT applications. The establishment of the public service demands will facilitate the assessment of the IoT's suitability as a solution and for the identification of the necessary objects to enable the connectivity of things. The following concerns the variables involved:

- Name of the objects connected with IoT: the connectivity names of the connected objects should be described: mobile devices (tablets, smartphones, smartwatches), smart homes, wearables, drones, household appliances, cameras, monitors, and other objects;
- The name of the IoT connectivity of the objects to be assessed, including radio frequency identification tags (RFID), artificial intelligence, machine-to-machine communication (M2M), vehicle-to-vehicle (V2V), sensors, actuators, nanotechnology, and others.

4.4.3. Strategic Digital City Construct

(a) Municipal or city strategies subconstruct

This subconstruct refers to the strategies or paths established by the municipal public administration to achieve public objectives, from the most basic to the most complex and innovative. These will take the form of projects, programs, plans, and actions to be mapped by themes or municipal thematic and then formalized and implemented through municipal strategic planning or government plans. The following concerns the variable involved:

- Number of municipal strategies: Analyzing how many strategies the municipality has in place for municipal public services offering connected via IoT.

(b) Municipal public services subconstruct

In the context of a strategic digital city project, it is important to identify whether the most diverse digital media and public services are oriented through the municipal administration. It should be emphasized that a service design proposal must be much more informative but interact with and solve citizens' problems and assess whether this public service can be facilitated by an IoT connectivity solution. The following concerns the variables involved:

- Number of municipal public services: it should be described how many requests for public services are received from digital citizens and whether these can be offered using information technology resources;
- Name of the theme of the municipal public services: it should describe to which municipal themes the public services based on information technology resources pertain.

(c) Information technology resources subconstruct

This subconstruct elucidates the infrastructure and technology resources necessary for the strategic digital city to function effectively. These resources encompass hardware, software, telecommunications systems and data, and information management systems. These resources must integrate the citizens with the municipal public administration or even other citizens within the urban context, thereby enhancing quality of life. The following concerns the variables involved:

- Name of the information technology resources: the names of the computer resources involved in providing municipal public services requested via software e-Sic by the digital citizen should be identified and described.

(d) Municipal information subconstruct

This subconstruct is fundamental for public managers to acknowledge which strategies to deploy and the types of public services regarding certain themes and users. There are legal demands and obligations, such as the Access to Information Act and the Transparency Portal, to provide information that citizens request or to justify and give transparency to public spending, such as the municipal public budget and tax collection, among others from different functions, such as public utility information, weather, traffic, climate and the operation of municipal public services. The following concerns the variable involved:

- Quantity of municipal information: Assessing how much municipal information is received by software e-Sic and if it is useful for the manager to decide whether to offer a public service or not.

All constructs, subconstructs, and active and integrated variables allow the framework to function fully and facilitate decisions by citizens and municipal managers, contributing to the urban and rural management of the city.

4.5. Framework Security

The proposed framework meets the concerns of database security and cyber-attack risks and respective technological challenges, which are being mitigated essentially by information controls and using the information technology resources available at the City Hall.

The proposed framework underscores the imperative for robust IoT to reinforce security measures in public service activities and to mitigate cyber threats [133]. Pinpointing vulnerabilities in prevailing frameworks steers the development of more secure IoT environments, thereby mitigating the risk of cyberattacks in the public domain. In addition, the proposed framework's practicality for real-time applications and resources is highlighted, ensuring secure communication in IoT systems. The protocol's resilience against prevalent attacks, such as replay and forward secrecy, ensures reliable security enhancement for IoT devices, which is imperative for preserving data integrity and privacy [134].

The study's framework for examining security risks in public communication networks facilitates organizations in proactively addressing potential threats, thereby ensuring the resilience of their IoT infrastructure. Furthermore, by emphasizing the significance of data-driven approaches in contemporary public enterprise management, the study provides guidance on the adoption of IoT to enhance network security [135].

Also, the proposed framework highlights the necessity for municipality-specific strategies to improve IoT adoption, considering factors such as trust, security, and social influence. Then, the insights derived can inform policymakers and institutions in developing frameworks that address the unique challenges and opportunities present in different urban environments, thus promoting effective IoT adoption [136].

Finally, the framework's enhanced public operations and favorable convergence performance render it suitable for large-scale IoT deployments, ensuring efficient and secure data aggregation [137]. By addressing diverse challenges and proposing an innovative approach, the framework offers sound practical implications that can guide the development and implementation of more secure, efficient, and user-friendly IoT systems in government public activities. Researchers at universities and professionals in companies continue to create, adjust, and expand security requirements in IoT environments, including incident detection and respective actions [138].

Future research in the city, in progress, should continue to explore these challenges, with a focus on enhancing the adaptability, scalability, and robustness of IoT applications to meet the evolving requirements to further improve and expand the quality of services offered to citizens throughout the city and region.

5. City Applicability and Discussion

To comprehend the functionality of the proposed framework, an analysis was conducted of the information flow received through the municipality's official channel for receiving requests from citizens, given that this is the sole official electronic means of receiving information from citizens. The municipal strategic plan (2018–2040) and the government plan for 2021–2024 were also analyzed. The data analysis covered the period from January to December 2021, during which the 22 municipal departments that received the most requests in 2021 were environment, finance, and health, followed by transport and traffic, public transport and public labor, and urban planning, involving diverse municipal issues. It is important to note that the software e-Sic channel (http://www.sjp.pr.gov.br/sic/ (accessed on 19 November 2024)) is a platform on which citizens can register a variety of requests, including compliments, suggestions, expressions of gratitude, complaints, claims, and information requirements, as well as provision of public services solicitations.

For this research, requests for the provision of municipal public services registered in the subject field as new requests in the software e-Sic system were considered. An initial analysis of the 3615 requests registered revealed that 2377 were listed as other matters and were excluded due to the absence of detailed information about the solicitation. Regarding detailing the subjects, the 286 existing subjects were refined and linked to the 26 municipal themes found. The analysis thus determined that the most prevalent municipal theme was health, followed by environment, social, labor, and finance.

A secondary analysis of the software e-Sic report revealed that of the 3615 records classified as requests for public services, 237 referred to other matters, and 131 were unspecified miscellaneous issues, then excluded because there were no details to classify them as requests for public services. This analysis left 3247 requests, involving 176 subjects, for further investigation into the utilization of information technology resources and the Internet of Things (IoT) in facilitating access to public services for the digital citizen. Of the 176 subjects that generated 522 requests, 103 were found to be unable to use information technology resources, while 73 were found to have the capability to do so, albeit with only 29 being provided by an IoT solution. This is due to the expectation that some connected objects to the network would be used to provide these municipal public services directly to digital citizens. Of the 29 public services most requested by digital citizens and which could be delivered by the IoT, 8 are not foreseen in the government plan, namely vaccination, traffic inspection, parking, noise pollution, measurements and confrontation of plots, public rubbish bins, museums, and geoprocessing. This finding is particularly salient considering the absence of provisions for addressing citizens' needs who have registered their requests through the software e-Sic platform, both within the government plan and in the municipal strategic planning. The conclusion drawn from this is that there is a dearth of planning and strategies tailored to meet the digital population's expectations.

The findings of the conducted experiment within the municipality of São José dos Pinhais demonstrated that digital citizens use the software e-Sic portal frequently, especially in the context of requests for municipal public services. These requests constitute nearly 50% of the total registered volume and encompass 26 distinct municipal themes. Then, regarding the use of information technology resources, it was found that 73 municipal public services can be provided to citizens using these resources, and 29 of the digital citizens' needs can be met using IoT. This confirms the viability and feasibility of the framework proposed by the case study experimented.

Subsequently, when analyzing the implementation phase of the framework, all the public services demanded by digital users in the experiment were evaluated, as well as the public motives that support their provision through IoT, whether in the municipality's strategic plan, government plans, or legislation. It is noteworthy that three public services

through IoT, despite the duty to provide the service through the municipality, at some point in their provision, state intermediation by public authorities was manifested due to the competence provided by Brazilian legislation, namely policing, sewage system, and public security. A closer look at the 29 preferences for requesting public services reveals that 14 of these fall under municipal themes, with the most prevalent involving health, the environment, security, and traffic concerns.

In addressing the theme of municipal governance, utilizing the concepts of leadership, strategy, and control as the unit of measurement, it is evident that in most cases, there is the presence of more than one municipal governance for a single digital citizen preference. Regarding the names of the objects to be connected and in order to facilitate the provision of public services through IoT, the criteria encompassed the entire spectrum, from the request for the service by the digital citizen to the final provision of the service. This can take the form of mobile devices (tablets, smartphones, smartwatches), smart homes, wearables, drones, household appliances, cameras, and monitors, being the use of sensors not foreseen in two services only: measurements and confrontation of plots and geoprocessing activities. Also, the remaining of this research will involve the use of sensors, as well as other types of connectivity, including radio frequency identification tags (RFID), artificial intelligence, machine-to-machine communication (M2M), vehicle-to-vehicle (V2V), sensors, actuators, nanotechnology, among others.

The analysis of the strategic digital city construct involved the subconstructs of municipal or city strategies, municipal information, municipal public services, and information technology resources. In the context of municipal strategic planning, the six strategies are subdivided into 33 actions or strategic objectives. However, a lack of clarity regarding the municipal themes to which these actions and objectives belong was identified. In the government plan, the four strategies are subdivided into 167 actions, which fall under the municipal themes: social, culture, education, sports, leisure, health, security, agriculture, innovation, labor, housing, infrastructure, tourism, environment and sustainability, transport, and urban mobility. The municipal information subconstruct shows that in 2021, there were 752 requests for information involving 131 of the 286 general issues and the most diverse municipal themes, with the most frequent requests being vaccinations, buses, 'other subjects', public tenders, land use tax, social security and pension, business licenses, municipal decrees, electronic invoices, noise pollution, health surveillance, and certificates.

The 3247 requests analyzed for the provision of public services by digital citizens via software e-Sic were divided into 177 subjects; the 10 most requested were social security and pension, refuse (building rubble), tree pruning, street lighting, traffic signs, land clearing, refuse (plant waste), land use tax, vaccinations, accumulation of refuse, objects or waste, with issues involving refuse receiving particular attention. Regarding the nomenclature of the municipal themes of these services, the most prominent are those involving finance, the environment, municipal services, traffic, and health, as indicated by the volume of requests from digital citizens.

The analysis of the nomenclature of information technology resources revealed 73 requests for municipal public services registered via the software e-Sic that utilize IT resources and may or may not employ IoT. Of these, the names electronic portal, application, customer service office, software e-Sic, social media (social networks, messaging application), or others sometimes appeared together in a single service, giving digital citizens the option as to which way they want to access for the selected public services, or isolated as the sole alternative access or provided by the municipal government. Consequently, ten municipal strategies have been formulated to support the utilization of the IoT in the provision of 26 municipal public services that employ or have the potential to employ information technology resources.

Finally, the original framework research demonstrated that, despite the absence of a specific prediction of the total implementation of the IoT in the provision of municipal public services in São José dos Pinhais, the analysis has identified potential opportunities for its integration. From this, 3247 user preferences are already digitized for the provision of 26 public services that can use the IoT, 10 municipal strategies that can include information technology resources, and three public motives that can enable the decision of the municipal public manager, which bring the optimization of public spending, the effectiveness of the municipal public administration and the quality of life of all citizens.

Even though the proposed framework has not been fully implemented but only partially implemented due to technological, political, and budgetary restrictions, there has been an evolution in the social and technological alternatives already available, which will be further expanded as adjustments are made to municipal services and available information, with increasing contributions to the decisions of citizens and municipal managers. Implementation is currently being worked on in the new municipal administration 2025–2028, with the creation of the Municipal Secretariat for Innovation, Modernization, and Digital Transformation (Decree 6428/2025), giving autonomy to strategies and projects related to information technology resources, including IoT. It is also worth noting that the city has a Commitment Term with the Brazilian Agency for Industrial Development (ABDI) to apply new technologies and create favorable environments for citizens. All these municipal actions reiterate the city's efforts to plan and execute information technology strategies, including IoT, considering the multiple digital inclusion policies that have substantially benefited the citizens of São José dos Pinhais.

6. Conclusion

Considering the continual rise of cities and the resulting increase in metropolitan population, urban administration needs to prioritize citizens' well-being. This can be accomplished through municipal initiatives that incorporate public services that require less physical presence, provide long-term savings in public expenditure, and optimize efficiency through the appropriate use of information technology resources. A connectivity environment that deploys information technology resources to provide public services adequately and effectively enhances the quality of life of urban and rural residents is required.

The research objective was achieved with the creation and application of the original framework with constructs, subconstructs, and variables experienced in a city.

The research results have demonstrated that the assets for providing municipal public services through the Internet of Things in the municipality are extant since the public motives already exist. The utilization of IoT connectivity then holds the potential to address the digital citizen's needs, given that the variables observed are contingent on the flow of information provided by the citizens during the process of requesting municipal public services.

The original framework was effective in the city research, providing adequate results in an IoT connectivity environment despite the restrictions described in the research discussion.

The research contributions are directed to the city that participated in the study, applying the framework with constructs, subconstructs, and variables, corroborating the provision improvement of municipal public services in line with the public motives and citizen's needs. For the public management of the city studied and for the City Hall, there is the contribution of the case experiment, which demonstrated the framework applicability and enabled greater adequacy in the provision of municipal public services offered through IoT, which are among the preferences of digital citizens, according to municipal governance approaches. For academia and strategic digital city research groups, the contribution is related to the example of the creation and application of a framework related to IoT

technologies in cities, highlighting the opportunity for future research to integrate IoT applications in their investigations on urban management and viable relations with strategic digital city projects. For citizens, the research contributed to favoring the effectiveness of municipal information and public services, strengthening the democratic process by accepting decisions and citizens' needs. This approach ensures that city management strategies adapt to the dynamic requirements of modern city and citizen life.

The research limitations are mainly due to the framework being applied in a single city since it was chosen as action research that required researchers to work for many years to monitor the reality of the citizens involved. Another limitation, defined by choice and through a research protocol, is the exclusion of citizens who do not use official digital channels to communicate with the municipal public administration. Furthermore, a limiting challenge was the lack of consideration of the municipal manager's perspectives regarding the provision of public services through IoT in São José dos Pinhais. Given that this framework was tested in a single municipality in Brazil, it may yield novel research findings in other cities in Brazil or abroad. However, the behavior of the research variables in the proposed framework cannot be generalized. The selected research variables contemplated the four subprojects of the strategic digital city in detail, and the risks of using IoT in the provision of municipal public services were analyzed within the technological limitations of the City Hall. A further criticism of the municipal public services framework created is that there are doubts as to whether information technology resources and the use of IoT represent a pivotal solution to urban and rural problems. This is because in Brazil, even though there is a national IoT plan, there is no exhaustive evidence of its use in public management, even the small number of publications and scientific research on this subject.

Future research could contribute to the representation and comparison of IoT-based public services implemented by various public institutions in different Brazilian and non-Brazilian cities. Such research could be incorporated into systematic literature reviews and benchmarking studies, hereby informing public sector managers on the adaptation of strategic management new and updated paradigms within the governmental context, considering the reality of each city and its citizens. In terms of variables defined in the research protocol, they can be reduced, increased, or altered at the discretion of those interested in the subject.

Municipalities must enhance their management practices by adopting information technology resources, thereby overcoming barriers and integrating the IoT into citizens' lives, irrespective of their digital proficiency. IoT is already a practical reality in urban centers, and its implementation can optimize city management.

The framework's applicability in urban settings is emphasized, as is the identification of other frameworks or models that utilize IoT to provide connected municipal public services. The example and possibility of including strategic digital city projects that involve connected municipal public services through the IoT in their strategies stand out for other municipalities. The framework's contribution and proposal for municipal public services utilizing the IoT, along with the methodology employed, its scope, and analysis of variables not explored in this research, remain for academia and research groups. Then, action research could be implemented to solicit diverse perspectives from public managers and citizens (and not just digital service users) regarding the research methodologies employed. This would facilitate the refutation, validation, suggestion, or modifications to the proposed framework.

Finally, there is scope to encourage greater citizen participation in public management through the utilization of information technology resources. This is underpinned by the necessity to recognize the digital citizen not only as a passive recipient of services but as an active contributor to municipal public management decisions and the popular will

for participation. For cities, it is essential to understand the steps necessary to realize the potential of the IoT in the delivery of public services. Moreover, municipal administration stands to benefit from demonstrating a commitment to forging closer ties with the citizens of São José dos Pinhais, given their existing familiarity with these, an understanding of their needs, the potential of IoT-driven public services, and their expectations.

The research conclusion reiterates that the framework of connected municipal public services using IoT is applicable in the strategic digital city context, thus enabling managers and public servants to manage the city effectively and improve citizens' quality of life. The provision of municipal public services through the IoT is a viable proposition in cities whose strategies can meet the needs of those who use public services. These are the users of the public space that is inhabited and called the city.

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