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Research Paper

Brazilian Smart Cities Through the Lens of Information Technology: A Systematic Mapping Study - Revisited and Expanded

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Abstract. [Context] The accelerated expansion of the urban population necessitates innovative and sustainable strategies to enhance the quality of life of citizens. In this context, smart cities leverage information technologies to collect, process, and integrate data, applications, and devices, thereby enabling intelligent, interconnected urban services. Despite the existence of numerous studies across diverse application domains, there remains a shortage of recent and comprehensive investigations that systematically organise the field and structure the application of information technology in smart cities, particularly within the Brazilian scientific community. [Objective] This article seeks to identify and systematically classify, according to the dimensions and indicators established in the ABNT NBR ISO 37122 standard, studies conducted by Brazilian researchers that examine the application of information technology in solutions for smart cities. [Method] A systematic mapping study was conducted in relevant scientific databases, covering 12 years of production (2014–2025). [Results] The findings reveal the concentration of studies by topic and application scenario, the temporal evolution of publications by type, the national institutions and the most influential researchers, as well as the international collaboration network and the main dissemination channels. [Conclusions/Contribution] The article provides an overview and an updated synthesis of smart city approaches developed by the Brazilian scientific community from the perspective of information technology.

Keywords: Smart city, Smart environment, Information and communication technology, Brazilian research community, ABNT NBR ISO 37122 standard, International collaboration.

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1 Introduction

The global scenario of population growth indicates that, since the first decade of this century, the number of inhabitants in urban areas has become the majority [United Nations and United Nations Population Fund, 2007]. Projections by the United Nations Department of Economic and Social Affairs estimate that, within 30 years (by 2054), the global population will reach 9,796 billion inhabitants [United Nations, 2024]. Urbanisation is a rapidly accelerating global phenomenon that challenges sustainable development, requiring innovative frameworks for understanding and managing urban complexity [Ochoa *et al*., 2024]. Coupled with the anticipated impacts of climate change, the process of urbanisation demands that cities provide efficient, sustainable, and adaptable public services to their citizens [Bittencourt *et al*., 2024].

In this context, smart cities represent an alternative to overcoming these challenges, as they employ Information and Communication Technologies (ICT) to deliver improved services and produce a positive impact on the lives of their citizens [Ullah *et al*., 2023]. Information systems supported by digital ecosystems are fundamental components for enabling such impacts and are foundational to a smart city. The academic and policy discussion on smart cities has been intensified in recent years, and Brazil is no exception to this broader trend. The Brazilian Letter for Smart Cities [BRASIL, Ministry of Regional Development, 2020] and the strategic study commissioned by the Chamber of Deputies [Júnior *et al*., 2021] reflect public authorities' concerns in discussing and promoting such initiatives. Furthermore, the Brazilian standard ABNT NBR ISO 37122 [2020] establishes a set of 80 indicators grouped into 19 dimensions to assess the progress and performance of cities towards sustainability and intelligence. In academia, the smart cities approach has been considered by the Brazilian Computer Society (SBC) to be an emerging topic related to the concept of Systems of Systems, whose development process is inherently challenging [Bernardini *et al*., 2017]. Furthermore, an important challenge discussed by the Brazilian research community is the interoperability and integration of applications within a "multi-organisational" context, in which systems from different organisations share data and functionalities [Neto and Frantz, 2025], demanding new requirements, particularly those related to security and privacy. Smart cities are an example of such a multi-organisational context that demands the interoperability and integration of public and private software systems.

Despite extensive investigations across various application domains, there are no recent and comprehensive studies that systematise the application of ICTs in Brazilian research on smart cities. Our work aims to fill this gap through a consolidated and updated analysis of national scientific production from 2014 to 2025. To achieve this objective, we conducted a systematic mapping study following the protocol outlined in the guidelines of Kitchenham and Charters [2007] and Petersen *et al*. [2015]. The selected studies were classified according to the 19 dimensions proposed by the standard ABNT NBR ISO 37122 [2020], taking into account

their application scenarios within the context of a smart city. Additionally, the studies were also categorised according to topics related to the field of ICTs.

As a result, we identified that between 2014 and 2018, Brazilian research on smart cities became more structured. We observed a steady increase in overall scientific output up to 2018, with a concentration of publications in conferences. From 2019 onwards, this volume stabilised until 2022; however, there was a significant growth in journal publications, suggesting a consolidation and maturity of this research field. Although the number of publications remained substantial, 2022 appears to indicate a downward trend in total output, which may be associated with the interdisciplinary nature of the field that gradually begins to collaborate and expand into other areas of knowledge. A large portion of the research problems addressed in the national context exhibits a transversal topic, meaning they apply to various urban scenarios. Moreover, application domains such as transport, governance, and public security also stand out with a higher concentration of studies. Our study reveals that the Brazilian institutional network is highly regionalised, concentrated in the three most populous regions of the country. We identified an international collaboration network, particularly with countries such as Portugal, the United States, and Italy, while collaboration with South American and African countries is virtually lacking. We also found that the topic of smart cities has attracted efforts from influential researchers in the field of computer science within the national context, and that there are numerous avenues for disseminating such work. Finally, we stress the importance of constructing a strategic agenda to consolidate digital transformation initiatives and strengthen the smart city ecosystem in Brazil. In our view, research on smart cities, through the lens of information technology within the Brazilian academic community, tends to deepen the debate on integration and interoperability among information systems, without compromising the security and privacy of data exchanged between distinct systems. Organisations, whether public or private, as well as citizens themselves, require technical guarantees of security and privacy as a means of encouraging data sharing for mutual benefit.

This work exhibits a strong consonance with the foundational tenets of Sociotechnical Theory [Sawyer and Jarrahi, 2014]. By conceptualising smart cities as complex configurations comprising technological, human, and institutional elements, the study aligns with the central proposition of Sociotechnical Theory that the performance and effectiveness of a system derive from the joint optimisation of its technical and social subsystems. This research investigates the deployment of ICTs to improve urban quality of life and service efficiency while explicitly avoiding a reductionist, technology-centric perspective. Instead, it systematically examines the challenges associated with integrating these technologies into the needs of citizens, as well as their behaviours, governance arrangements, and public policy frameworks, as illustrated by the analysis of security and data privacy issues and the emphasis on a strategic agenda for digital transformation, which still lacks in many cities. This comprehensive and integrative standpoint, which foregrounds the interdependence of technical innovations and their broader social and organisational milieu, encapsulates the core of the sociotechnical approach.

Unlike purely technological approaches, the holistic perspective offered by Sociotechnical Theory provides a broader lens through which to understand how technical decisions (e.g., the use of mobility sensors) affect social practices (e.g., travel time, traffic safety) and vice versa. This perspective recognises that the success of a system depends as much on social acceptance as on technical efficiency and, in the context of smart cities, this means that it is insufficient merely to install IoT devices or digital platforms without considering how citizens, public managers, and organisations will engage with them. Equally, in smart cities, public policies, cultural habits, and digital infrastructures evolve in an interdependent manner, reinforcing the relevance of a sociotechnical perspective for analysing how social, organisational, and technological dimensions mutually influence one another.

It is important to note that, in the present study, the observation period was extended relative to the previous publication (Boniati and Frantz [2026]), so as to include all pertinent works published throughout the entire year 2025. The review of related literature was also broadened, and a synthesis table was incorporated to systematise the main contributions. The principal contribution of this study, however, lies in the formulation of a new research question that investigates the structure and dynamics of the international collaboration network underlying Brazilian research on smart cities. Table 1 provides a summary of the main changes and additions in this version of the journal. The remainder of this article is organised as follows: Section 2 presents important concepts for understanding the work. Section 3 introduces ten recent systematic literature mappings on topics related to smart cities that employ information technology resources. The methodological protocol and the criteria adopted to select and classify the studies are described in Section 4, and the implementation of the mapping study is detailed in Section 5. Finally, Section 6 presents the discussions of the results, and Section 7 outlines the conclusions and future work.

2 Background

This section introduces key concepts that support the comprehension of this article. Section 2.1 addresses the fundamental concepts related to Smart Cities, while Section 2.2 examines the role of ICT within this context.

2.1 Smart Cities

Cities are urbanised spaces that concentrate individuals and provide the necessary infrastructure for the settlement of these populations. Soto *et al.* [2016] characterise cities as heterogeneous structures that share the urban space and public infrastructure with their inhabitants or service providers. The problems arising from accelerated urbanisation processes (common in cities around the world) have given rise to the concept of the smart city as an alternative to enable the intelligent use of resources and thus improve the quality of life of their inhabitants [Esposte *et al.*, 2017]. The main objective of a smart city is to address urban problems efficiently in order to enhance the sustainability of the city and the quality of life of its inhabitants [Monzon, 2015]. Global crises, such as the COVID-19 pandemic, also drive the smart city paradigm as they explore the potential utility of solutions to cope with complex events [Zhao *et al.*, 2021].

Table 1. Summary of Changes and Additions in the Journal Version

Additions in this journal version	Section
Inclusion of a background section.	Section 2
The number of related works was increased (from 5 to 10 studies) and a summary table was added.	Section 3
Detailed methodology (inclusion of figure to illustrate the stages of the systematic mapping process).	Section 4
Extension of the study period until 2025.	Section 5
Provided more details on the search strings used in each database.	Section 5
Add a new research question to investigate international collaboration.	Section 5
The discussion section was expanded with a sociotechnical perspective (Section 6.1) and the practical and theoretical implications for actors in the smart city ecosystem (Section 6.2).	Section 6

According to Rubio *et al*. [2016], the transformation of conventional cities into smart cities requires the adoption of a systemic thinking approach that makes it possible to identify and manage the interconnections among the various subsystems that compose the city ecosystem. In this regard, Nam and Pardo [2011] characterise a smart city as an urban system capable of continuously monitoring and integrating the status of its critical infrastructures, optimising resource utilisation, strategically planning preventive maintenance activities, and systematically overseeing safety-related dimensions, while concurrently maximising the quality and efficiency of services delivered to its inhabitants.

Bria and Morozov [2020] argue that the notion of "smart" should not be reduced to its technological dimension (i.e., a city with more technology is not necessarily smarter than another). The defining characteristic of a smart city lies in the ways in which technology is deployed and in the distribution of control over its benefits. According to the authors, a city saturated with sensors and algorithmic systems primarily constitutes a space of continuous data extraction, surveillance, and behavioural modulation. Conversely, when a city is oriented by principles of technological sovereignty and meaningful citizen participation, it can be considered genuinely intelligent. This conception of a smart city is consistent with the premises of Sociotechnical Theory [Sawyer and Jarrahi, 2014], namely, that endowing a city with technological infrastructure is insufficient for it to be truly intelligent; instead, a multidimensional assessment is required, examining how technological infrastructures shape social dimensions such as governance, social inclusion, justice, and participation.

Smart cities constitute a multidimensional research theme that organically involves technological, human, and institutional components [Nam and Pardo, 2011]. The development of solutions for smart cities requires a multidisciplinary perspective and frequently demands the integration of multiple technologies [Peralta Abadía *et al*., 2022]. Despite the coexistence of numerous definitions of smart cities, Schiavo and de Magalhães [2022] explain that, regardless of the breadth and diversity of such concepts, certain terms are recurrent, such as quality of life, services, citizens, and information and communication technologies.

2.2 Information and Communication Technologies

Information and Communication Technologies (ICTs) encompass a broad spectrum of digital tools, systems, and platforms that enable the processing, transmission, storage, and retrieval of data, thereby facilitating the exchange of information among individuals, organizations, and social groups. This encompasses a wide range of devices, applications, and networks. According to UNESCO [2026], the effective and accessible use of ICTs can foster an inclusive digital transformation within society. In this work, we consider ICTs to comprise the entire spectrum of technological and digital artefacts, including hardware devices, software platforms, telecommunications infrastructure, algorithms and techniques for software engineering, and other digital tools that may be employed to catalyse innovations in smart cities.

As discussed in the previous section, the smart city paradigm is operationalised through the integration of multiple intelligent solutions that collectively aim to enhance quality of life, increase operational efficiency, and foster sustainable development. Over time, a wide range of intelligent systems has been proposed to address urban challenges across diverse application domains. According to Goumopoulos [2024], this heterogeneity of systems is enabled by a broad set of underpinning technologies, among which ICTs are particularly prominent. Tcholtchev and Schieferdecker [2021] further argue that ICTs constitute the fundamental infrastructure for these intelligent solutions, facilitating the acquisition, transmission, and real-time processing of data, thereby improving various urban services and advancing the overarching vision of smart cities.

3 Related Work

Our review of the literature has identified ten systematic mapping studies conducted by Brazilian authors on topics related to smart cities between 2020 and 2024. Table 2 summarises these studies. Our mapping differs from these works in two main aspects: thematic breadth and scope. Firstly, it relates to the fact that the related studies examine specific topics within the smart city context, such as software engineering, architectures and platforms, ubiquitous computing, data management, and security and privacy. In contrast, our systematic mapping broadly investigates the application of ICTs in the smart city context, thereby encompassing a wider range of topics. Secondly, our mapping focuses on the national research environment. To this end, we selected studies published exclusively by authors affiliated with Brazilian institutions, aiming to map the national research landscape on smart cities involving ICTs resources. In contrast, the systematic mappings identified and reported in this section are not limited to national studies.

The studies by Lopes *et al*. [2020] and Machado *et al*. [2020] explore concerns related to Software Engineering in

the context of smart cities. Lopes *et al*. [2020] analyse the current state of research regarding software testing for the domain of Systems of Systems (SoS), which are employed in smart city infrastructures. The study examined 37 publications and identified tools, approaches, methods, and processes addressed in the literature for testing SoS. It concluded that software testing for SoS still faces several challenges and presents many unresolved issues, particularly in the definition of processes and metrics. Machado *et al*. [2020] analysed eight articles the aim of identifying the product quality attributes considered in the evaluation of applications within the smart city context. According to the authors, the development of applications for smart cities involves numerous specificities (e.g., processing and analysis of large volumes of data, context awareness, perception and interaction with physical elements of the city, and maintenance of citizen privacy and security, etc.), and it is necessary to ensure that such applications meet an adequate level of quality to enable their daily use. The study concludes that more detailed specifications of attributes are needed to ensure the quality of smart city applications.

The studies by Souza *et al*. [2020] and Nascimento *et al*. [2021] explored the paradigm of ubiquitous computing to enhance computational applications within the context of smart cities. Souza *et al*. [2020] analysed 87 publications to identify and categorise technological solutions (tools, services, applications, or products) for urban public monitoring through ubiquitous devices in smart city environments. According to the authors, most studies consider urban public monitoring via ubiquitous devices to be a significant trend in the smart city context. Furthermore, the authors highlight that the accuracy of ubiquitous devices and their energy efficiency are key challenges to be addressed. Nascimento *et al*. [2021] provide an overview of context recognition approaches applied in smart city domains. The authors analysed 93 studies and found that *smartphone* sensors are the primary source for context acquisition. Additionally, they identified that supervised learning is the most commonly used approach in contextual reasoning techniques, and that indoor and outdoor environment detection are the most prevalent applications of location recognition. According to the authors, deep learning techniques and "non-GPS" methods are emerging trends with important open questions.

Techniques and tools for data management involve activities such as collection, processing, interpretation, and visualisation, and hold significant potential for smart city applications. The articles by Silva *et al*. [2021] and Barbosa *et al*. [2023] discuss aspects related to data management in these contexts. Silva *et al*. [2021] presents a systematic mapping study covering 37 studies, focusing on the use of geotechnologies in the context of smart cities. The authors aimed to identify which problems are addressed by geotechnologies, the specificities of their use, and which proposals have been implemented by public authorities. The study found that software-based solutions are the most prevalent, with Geographic Information Systems being the most frequently cited geotechnology. In governmental contexts, applications are primarily related to urban planning, followed by mobility and energy solutions. The article by Barbosa *et al*. [2023] considers that information derived from smartphone connection records (Call Details Record – CDR) generates large volumes of telecommunications data, creating an opportunity to support smart city management. In that study, 72 works were analysed in which CDRs are used to support smart city control centres. The use cases were grouped into categories of smart services, with most studies focusing on mobility and urban planning. According to the authors, monitoring mobility patterns is extremely valuable, as it offers an opportunity to redesign public transport systems or better plan the introduction of new mobility services. The study concludes that there are challenges to be overcome regarding the use of CDRs in smart city applications, particularly the development of techniques that ensure data privacy and user anonymity, given that such records contain sensitive personal information, such as location and communication patterns. Another challenge concerns the availability and coverage of telecommunications infrastructure, which still requires improvement, especially in remote or underdeveloped regions.

The studies by Silva *et al*. [2022] and Almeida *et al*. [2023] explore computing architectures and platforms that specify how systems are structured, including their layers and supporting components. Silva *et al*. [2022] conducted a systematic mapping study encompassing 17 articles to provide a comprehensive understanding of the Fog Computing paradigm in the context of smart cities. This paradigm is characterised by a horizontal system-level architecture, in which devices located near end users and IoT devices are utilised for processing, storage, and networking functions. The authors explain that development platforms for Fog Computing solutions offer services and abstractions designed to integrate data from IoT devices and various deployed information systems, thereby simplifying the development of smart city applications. The article highlights numerous open issues, particularly the lack of standards for interoperability and programming across platforms, the absence of simulators and testing environments, concerns related to data security and privacy, and the need to reduce energy consumption of architectural components, among others. Almeida *et al*. [2023] conducted a systematic mapping study encompassing 13 primary studies to investigate which middleware strategies and technologies are employed for Digital Twin applications, currently regarded as an innovative concept for supporting computational applications in industry, healthcare, and smart cities. The authors found that the use of middleware to support DTs remains in an early stage, with most of the analysed studies focusing on basic aspects of data services. These middleware solutions primarily address data acquisition, importation, and storage, while neglecting aspects such as data transformation, data aggregation, time-series storage, and ontology management. The study also revealed open issues concerning synchronisation problems for real-time bidirectional communication between a DT and its counterpart in the physical world, as well as concerns related to information security in this context. The use of computational intelligence is also identified as a research gap, having been only superficially explored by a limited number of studies.

Security and privacy-related aspects have been recurring topics in studies within the smart city context. According to Pinto *et al*. [2024], data collected from IoT devices serve as key sources of information for smart city applications; however, collecting personal data raises challenges concerning

privacy protection. In that study, the authors investigated 49 primary studies to provide insights into privacy evaluation in the IoT context, with a specific focus on findings involving Personal Data Store solutions. The mapping indicates a growing number of publications on the subject; however, few provide solutions to the problem of privacy in the context of the IoT. Specifically regarding the use of PDS, only two studies investigate this type of solution. Sobrinho *et al*. [2024] address smart cities as a vertical application domain enhanced by the deployment of 5G infrastructure, considering cybersecurity aspects. The authors explain that 5G applications in smart cities introduce new challenges and specific security and privacy requirements, given that key components of this technology are software-based. In that study, 389 articles were reviewed, and the results indicate a wide range of vulnerabilities as well as the existence of proposed solutions. One of the most pressing open challenges concerns attacks that may maliciously exploit the high computational capabilities of quantum devices to access private data, particularly through insecure data transfers on IoT platforms.

4 Research Protocol

The research protocol we adopted in this systematic mapping study is grounded in the protocols proposed by Kitchenham and Charters [2007] and Petersen *et al*. [2015], and is concisely described in this section. The protocol that guided our study comprises five main stages, they are: definition of research questions, search, analysis and classification, results and discussion, and threats to validity. Figure 1 illustrates there stages, which are detailed below. The first stage clarifies the purpose of the mapping by defining the research questions to be addressed. The next stage involves conducting the search and selecting the articles to be included in the study. In the third stage, the articles are analysed and classified according to the research questions established during the initial phase. The information extracted during classification is then examined in the fourth stage. Finally, the last stage assesses potential threats to validity that may affect the results.

4.1 Definition of research questions

According to Petersen *et al*. [2015], the research questions are directly related to the objective of the systematic mapping. The formulation of research questions serves as a guide for the subsequent stages, from defining search criteria to analysing the selected studies. There is no minimum or maximum number of research questions, and depending on the study's needs, they may be more generic and broad, or more specific. In Kitchenham and Charters [2007], a strategy composed of a set of criteria is described, known as PICOC (an acronym for Population, Intervention, Comparison, Outcome, Context), which can be used to guide the formulation of the study's objective and its research questions. This strategy seeks to objectively address the following criteria:

- **Population**: The target group of the study.
- **Intervention**: The approach to be investigated.
- **Comparison**: The alternative to the approach for comparison purposes (optional).
- **Outcome**: The expected results of the study.
- **Context**: The environment in which research is applied.

4.2 Search

In the search stage, it is first necessary to define the search string containing combinations of keywords that enable the appropriate retrieval of a preliminary set of studies. The responses provided to the PICOC strategy criteria help identify the most relevant keywords. Next, it is necessary to select the scientific databases in which the search string will be executed. These databases are public or private repositories that store information about scientific publications. The selection of databases should consider the scope and thematic coverage of the published studies, as there are both national and international repositories, as well as repositories specialised in specific areas of knowledge. Moreover, the choice of repositories may be influenced by the functionalities they offer for conducting searches and exporting results. In general, databases provide an interface through which the search string can be entered and processed. Syntax rules for specifying the search string may differ across databases, and in such cases, adaptations must be made.

Executing the search string in the respective scientific repositories will result in a preliminary set of publications that meet the specified criteria. From this point onwards, researchers must manually apply inclusion and exclusion criteria, based on information retrieved by the search engines, to identify the relevant and final set of publications to be considered in the study. Preliminary reading of data, such as titles and abstracts, is necessary to determine which publications should be included or excluded. Additionally, certain exclusions based on objective criteria may be applied to the preliminary set, such as the period, language, or availability of the publications. The use of multiple scientific databases is important to broaden the scope of the search; however, in such cases, the same article may be indexed in more than one database, requiring the removal of duplicates.

In addition to executing searches in scientific databases, Petersen *et al*. [2015] mention other strategies that may be used complementarily to manually include articles: the inclusion of known studies and the snowballing technique. In the first case, relevant and well-known articles identified by the researchers, which are not indexed in the selected databases, are manually included. In the case of the snowballing technique, researchers examine the bibliographic references of the pre-selected articles with the aim of identifying relevant publications that were not captured by the initial search, and, if applicable, include them manually. The outcome of the search stage is the final set of articles to be mapped in the study.

4.3 Analysis and classification

In this stage, the set of publications selected during the search is analysed and classified. The research questions serve as a reference for identifying relevant data and information to be extracted (e.g., year and place of publication). The classification of studies is considered a central step in systematic mapping studies. Depending on the research questions to be addressed and resource availability, Petersen *et al*. [2015] suggest using an existing classification scheme, as this facilitates comparability across systematic mapping studies. Another option, as explained by Petersen *et al*. [2008], involve developing a classification scheme based on the selected studies.

Table 2. Related Mapping Studies in the Literature.

Article	Nº. of publications mapped	Field	Subject
Lopes *et al*. [2020]	37	Software Engineering	Software Testing
Machado *et al*. [2020]	8	Software Engineering	Product Quality
Souza *et al*. [2020]	87	Ubiquitous Computing	Urban Public Monitoring
Nascimento *et al*. [2021]	93	Ubiquitous Computing	Context Recognition
Silva *et al*. [2021]	37	Data Management	Geotechnologies
Silva *et al*. [2022]	17	Architectures and Platforms	Fog Computing
Almeida *et al*. [2023]	13	Architectures and Platforms	Digital Twins
Barbosa *et al*. [2023]	72	Data Management	Cellular Infrastructure
Pinto *et al*. [2024]	49	Security and Privacy	Privacy in IoT
Sobrinho *et al*. [2024]	389	Security and Privacy	Security in 5G networks

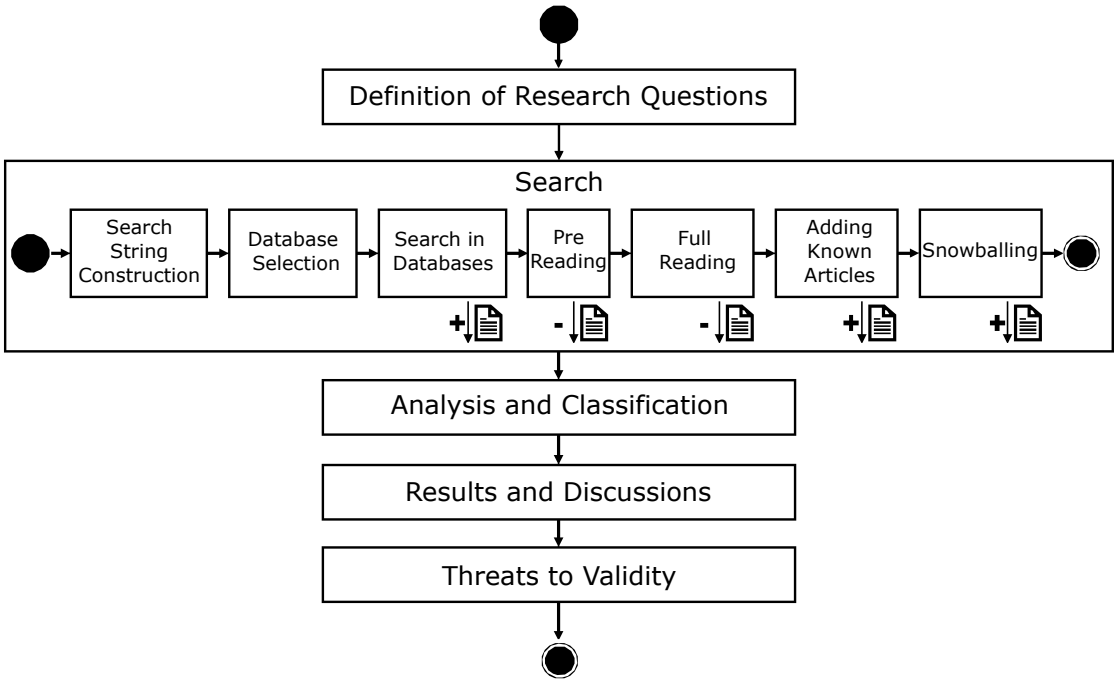

Figure 1. Stages of the systematic mapping process.

In this case, an initial review round is conducted in which abstracts are read to extract key words and concepts. At the end of this process, the identified terms are grouped and refined to create a classification scheme that will be applied in a second review round. After classification, the extracted data are used to generate charts and tables that support their analysis.

4.4 Results and discussion

This stage involves a systematic examination of the principal findings of the study, grounded in the charts and tables generated in the preceding phase. It comprises the interpretative analysis of the results, with particular emphasis on elucidating and emphasising the most salient information. Through this analytical discussion, it becomes possible to identify key challenges, emerging trends, and unresolved research gaps within the thematic domain under investigation.

4.5 Threats to validity

In systematic mapping studies, it is appropriate to discuss the existence of threats to validity, i.e, potential factors that may compromise the reliability, accuracy, and generalisability of the results. This stage presents the main threats to validity, as well as the strategies adopted to mitigate them throughout the various phases of the study. The work by Runeson and Höst [2009] explains that the validity of a study reflects the extent to which the results are truthful and not influenced by the researchers' subjective viewpoints, and describes four aspects of validity:

- **Construct validity**: reflects the extent to which the operational measures studied truly represent what the researcher intends and what is being investigated according to the research questions.
- **Internal validity**: refers to the reliability of the selection and analysis process, that is, the degree to which the obtained results may have been influenced by biases or errors in the procedure.
- **External validity**: relates to the generalisation of the results beyond the set of analysed articles.
- **Reliability**: concerns the reproducibility of the study, reflecting the extent to which the data and analysis depend on the specific researchers involved.

5 Study Implementation

This section presents the application of the protocol previously described to conduct the study. We initially used JabRef software [1], which provides functionality for importing bibliographic data into a relational database. Once imported, the data were analysed and classified using queries, spreadsheets, and auxiliary interfaces developed to streamline study execution. The list of articles included in this mapping, along with the supporting charts and tables derived from it, are discussed in Section 6.

5.1 Research questions

The objective of this study is to produce a comprehensive review that systematises the use of ICTs in Brazilian research on smart cities conducted between 2014 and 2025. During the planning phase, the PICOC strategy was applied to support the formulation of the overarching research objective:

> *Present a comprehensive overview of how the interdisciplinary topic of "Smart Cities" (**intervention**) has been investigated by Brazilian researchers (**population**) within the domain of information technology (**context**), with particular attention to the temporal evolution of studies conducted between 2014 and 2025, the institutional network responsible for disseminating research findings (including patterns of international collaboration), the application scenarios and thematic challenges addressed, the most influential researchers and publications, and the principal forums for disseminating these results (**outcome**).*

Six research questions, formulated on the basis of the overarching research objective, structure and inform the subsequent stages of the study, as follows:

- **RQ1**: What is the numerical evolution of the articles published in the period 2014–2025?
- **RQ2**: Which are the main national research groups and what is their collaboration network?
- **RQ3**: What are the key international collaborations in Brazilian research on smart cities?
- **RQ4**: What are the main application scenarios in smart cities and the thematic interests of these Brazilian studies?
- **RQ5**: Who are the Brazilian researchers that stand out in smart city research?
- **RQ6**: In which conferences and journals are the studies published?

5.2 Search

To conduct the research, five scientific databases widely used in academic work within the field of computing were selected: ACM Digital Library [2], IEEE Xplore [3], Web of Science [4], Science Direct [5], and Scopus [6]. Based on the overall objective and the defined research questions, a broadly constructed search string was adopted, incorporating the term "smart city" along with its plural and Portuguese-language variations. Additionally, a condition was added to filter the authors' country of affiliation using the terms "Brasil" or "Brazil". Figure 2 illustrates the search string used in the different databases.

ACM Digital Library

```
(( Title:
    ("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
) OR ( Abstract:
    ("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
) OR ( Keyword:
    ("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
)) AND Affiliation:(brasil OR brazil)
```

IEEE Xplore

```
( (
  (  "Document Title":"cidade inteligente" OR
     "Document Title":"smart city" OR
     "Document Title":"cidades inteligentes" OR
     "Document Title":"smart cities")
  ) OR (
     ("Abstract":"cidade inteligente" OR
      "Abstract":"smart city" OR
      "Abstract":"cidades inteligentes" OR
      "Abstract":"smart cities")
  ) OR (
     ("Author Keywords":"cidade inteligente" OR
      "Author Keywords":"smart city" OR
      "Author Keywords":"cidades inteligentes" OR
      "Author Keywords":"smart cities")
  )
) AND ("Author Affiliations":Brasil OR
       "Author Affiliations":Brazil)
```

Science Direct

```
Title, abstract, keywords:
     "cidade inteligente" OR
     "smart city" OR
     "cidades inteligentes" OR
     "smart cities"

Author Affiliation: Brazil OR Brasil
```

Scopus

```
TITLE-ABS-KEY ("cidade inteligente" OR "smart city" OR
               "cidades inteligentes"  OR "smart cities" )

AND AFFILCOUNTRY ( "brazil" OR "brasil" )

AND LIMIT-TO ( SUBJAREA , "COMP" )
```

Web of Science

```
(
 TI=("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
 OR
 AB=("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
 OR
 AK=("cidade inteligente" OR "smart city" OR
     "cidades inteligentes" OR "smart cities")
) AND CU=(brasil OR brazil)
```

Figure 2. The search strings used in each database.

[1] https://www.jabref.org/
[2] https://dl.acm.org/
[3] https://ieeexplore.ieee.org/
[4] https://webofscience.com/wos/
[5] https://sciencedirect.com/
[6] https://scopus.com/

The literature search was performed on two separate occasions: initially on 26 April 2025, and subsequently, for the purpose of the update, on 2 March 2026. In total, 1916 publications were selected during the search, distributed across databases, as presented in Figure 3. Notice that, although the first search has been conducted on 2025, it has not included publications along 2025, which were only included in the second search conducted on 2026. The databases ScienceDirect, Scopus, and WoS allowed the application of additional filters related to the area of interest; in this case, the presented results already reflect the applied filter, focusing on the field of Computing. The search results were exported in BibTeX format. With the aid of the JabRef software, the contents of the BibTeX files were imported into a relational database for subsequent analysis and classification.

5.3 Analysis and classification

The classification and analysis were carried out in two complementary stages conducted by a single researcher. However, prior to their execution, the main attributes to be considered were defined based on the data retrieved during the search, along with additional information to be extracted manually. The tabulation of this data is important as it enables the objective application of certain inclusion and exclusion criteria. Using the data extracted from the databases, the following attributes were tabulated: type of publication (according to BibTeX classification[7]), year of publication, title, abstract, keywords, language, and the title of the journal, book, or event name. In addition to these attributes, the Digital Object Identifier (DOI) was also collected, which allowed for the identification of duplicate publications, i.e., those retrieved from more than one database. In total, only 41 publications lacked a DOI; in such cases, potential duplications were assessed manually. Overall, 1,129 unique publications were identified from the data extracted during the search.

In the first classification round, the set of unique publications was used, beginning with the reading of attributes such as 'title' and 'abstract'. Thus, inclusion criteria (i.e., conditions that ensure the publication remains in the set to be analysed) were assessed, as well as exclusion criteria (i.e., conditions that restrict the publication from being part of the study). Table 3 presents the set of inclusion and exclusion criteria applied in this study. For each excluded work, the corresponding justification was recorded (e.g., secondary study, study in another area, etc.). For each included work, a descriptive synthesis of the investigated problem was prepared (an attribute called "notes" with a limit of 256 characters) and the mapping of representative and indicative keywords of the proposed solution was carried out, forming the attribute called "theme/subject". Additionally, an optional attribute called "city" was collected when the study itself was conducted specifically in a given city. Regarding the authors, their full names and institutional affiliations (institution name, city, and country) were collected.

Before starting the second round of classification, the terms recorded in the "theme/subject" attribute were consolidated and normalised. This procedure aimed to eliminate redundancies and linguistic variations (such as singular/plural or synonyms), resulting in a controlled vocabulary. The terms were then separated into two broad groups: (i) those referring to application scenarios (for example, health, energy, transport) and (ii) those related to information resources and technologies, that is, concerning the technological solutions employed (e.g., artificial intelligence, telecommunications, etc.).

Table 3. Inclusion and Exclusion Criteria.

Criteria	Description
Inclusion	The study should address aspects related to ICTs within the context of smart cities.
	At least one of the authors must be affiliated with Brazilian institutions.
	The study must have been published between 2014 and 2025.
Exclusion	Duplicate articles.
	Secondary or tertiary studies.
	Books and/or book chapters.
	Articles with fewer than five pages.
	Articles representing conference abstracts, editorials, and mini-courses.

To classify the application scenarios, 20 dimensions were adopted; 19 of them came from standard ABNT NBR ISO 37122 [2020], which provides 80 indicators to be applied in smart cities. These dimensions encompass the following application scenarios: (1) economy, (2) education, (3) energy, (4) environment and climate change, (5) finance, (6) governance, (7) health, (8) housing, (9) population and social conditions, (10) recreation, (11) safety, (12) solid waste, (13) culture and sports, (14) telecommunications, (15) transportation, (16) urban/local agriculture and food security, (17) urban planning, (18) wastewater, and (19) water. The concept of "Cross-cutting" (20) was introduced as an additional dimension intended for the grouping of studies whose technological scope broadly extends across different dimensions of the smart city. A typical example would be the proposition of a communication protocol applicable both to traffic monitoring and to the management of water or energy distribution.

To classify the articles according to topics related to ICT, the feasibility of adopting consolidated classification schemes was initially assessed, such as the ACM/CSS [8], IEEE Thesaurus, and SWEBOK [9]. However, it was found that such schemes, although robust, presented limitations in the specific context of smart cities: overly broad categories could dilute relevant topics (e.g., Internet of Things or data management), while overly specific classifications could result in unrepresentative or empty groups. In view of these limitations, a thematic classification scheme was constructed, refined from the terms extracted in the first stage and inspired by the conceptual structure of ACM/CCS. The terms were analyzed based on their meaning and grouped with related terms, resulting in the following classification scheme, which was used during the second round of review:

1. **Artificial and Computational Intelligence**: techniques

[7] article, book, inbook, incollection, inproceedings

[8] ACM Computing Classification System

[9] Software Engineering Body of Knowledge

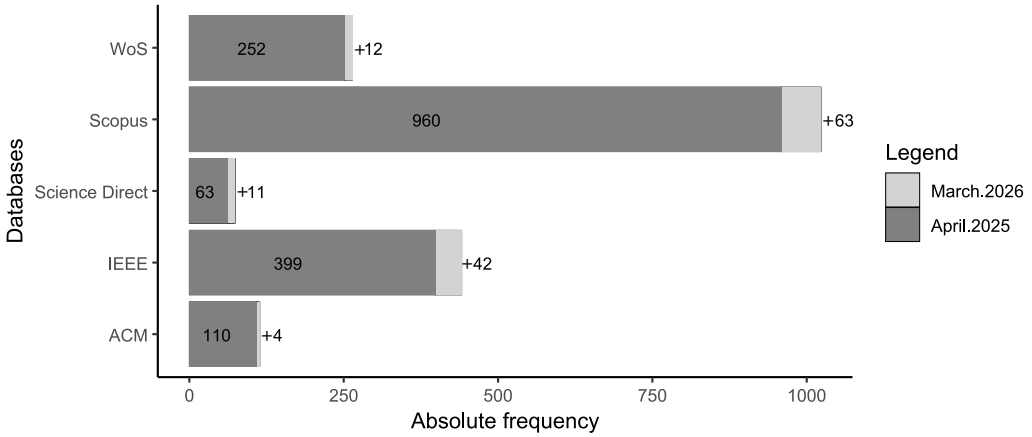

Figure 3. Frequency of articles per database.

for recognition, learning, and automated decision-making.

2. **Computing Architectures, Infrastructures, and Platforms**: how systems are structured, including their layers and supporting components.
3. **Data Management**: collection, organisation, processing, analysis, and interpretation of data.
4. **Internet of Things and Ubiquitous Computing**: integration of smart devices and objects into networks.
5. **Networks and Communication**: technologies, protocols, and topologies related to data transmission.
6. **Security and Privacy**: data protection, anonymisation, and digital identity.
7. **Sensing and Devices**: physical and digital devices used to capture data.
8. **Software Engineering and Systems Development**: methods, languages, and tools for designing, developing, and maintaining software.
9. **Standards, Models, and Governance**: formal structures for the development and operation of systems.
10. **User Experience and Interface**: interfaces between users and systems.

The adoption of a set of categories derived from the collected terms substantially reduced ambiguities in the second round of classification. Nevertheless, when a study offered contributions that could potentially fall into more than one category (e.g., the description of an architecture for urban data collection that simultaneously applies artificial intelligence techniques to support decision-making), a complementary analysis of the text was undertaken to identify the predominant research theme. In such cases, the classification was assigned to the category reflecting the principal technical-scientific contribution of the study, taking into account its objectives, the problem investigated, and the emphasis placed by the authors throughout the work.

5.4 Results of mapping study

At the end of the analysis and classification stage, following two rounds of review, 702 articles were classified and included in the study. A complete listing of these articles is available on GitHub [10]. In this section, the classified data will be presented in the form of figures and tables, grouped according to the research questions outlined in Section 5.1.

RQ1: Frequency of publications by year and type

During the research stage, as described in Section 5.2, no minimum or maximum publication period was defined. However, based on the extracted data, it was observed that the total number of works published prior to 2014 was only six, comprising five conference papers and one book chapter. The data analysis reveals a steady increase in the number of publications between 2014 and 2018, followed by a period of stabilisation. Between 2014 and 2025, 45.2% of the selected studies were published in journals, while 54.8% appeared in conference proceedings. Figure 4 illustrates the evolution in the number of publications by venue (journals or conferences) over the last twelve years.

RQ2: Brazilian institutions and their cooperation network

Considering the articles selected in this study, it is possible to observe that institutions from the Southeast Region participated in over 58% of the studies, followed by the Northeast Region with 44%, the South Region with 29%, and the Central-West and North Regions with 7% and 5% of the articles, respectively. The Federal University of Rio Grande do Norte (UFRN), located in the Northeast Region, had the highest participation in this study, appearing in 11% of the selected works, followed by the University of Campinas (Unicamp) with 9%, and the University of São Paulo (USP) with 8%, both from the Southeast Region. Also noteworthy are the Federal University of Minas Gerais (UFMG) and the Fluminense Federal University (UFF), both in the Southeast Region, with participation rates of 6% and 5%, respectively. In the South Region, the Federal University of Technology – Paraná (UTFPR) stands out with 5% participation, along with the Federal University of Santa Catarina (UFSC), which has 4%.

Figure 5 illustrates the network of relationships among Brazilian institutions conducting research on smart cities (the colours represent Brazil's regions, as indicated in the legend). To improve visual clarity, research centres and/or industry entities were not included in the figure. It is worth noting that among the research centres, the institutions with the highest number of publications in this study are the National Institute of Telecommunications (INATEL-MG), the Centre for Infor-

[10] `https://github.com/gca-research-group/isys-2026-smart-city`

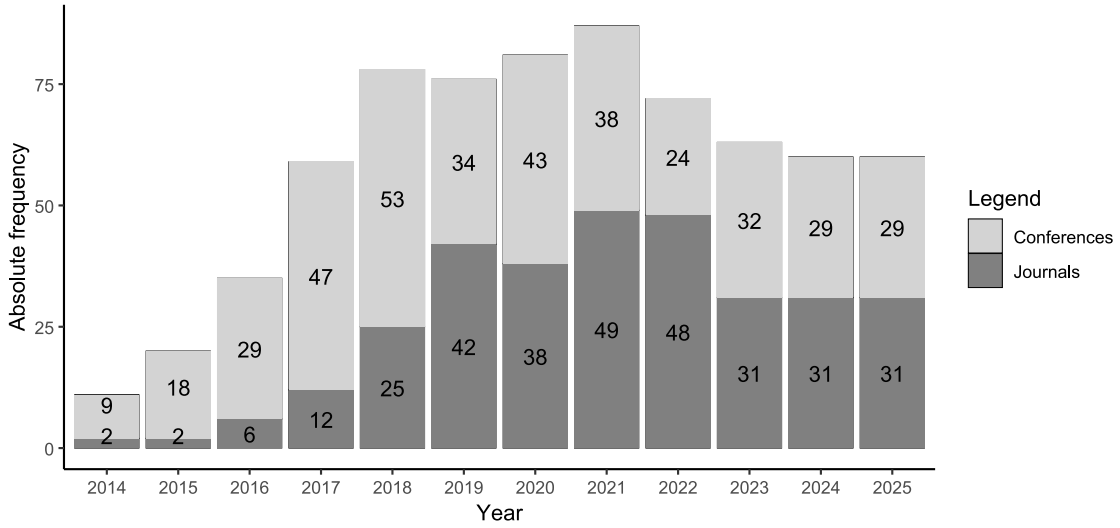

Figure 4. Number of articles per year and type of publication.

mation Technology Renato Archer (CTI-SP), and the Institute for Technological Research (IPT-SP), with participation in 8, 5, and 4 studies respectively, representing less than 1% of the total. An interactive version of the Figure 5 can be accessed through the VOSviewer Online tool [11]

RQ3: International Relations

Regarding international collaboration in Brazilian research on smart cities, we identified 53 distinct countries with joint publications involving researchers affiliated with Brazilian institutions. Portugal is the country with the highest number of joint publications (68), followed by the United States (35), Italy (27), Canada (24), Spain (22), India and Germany (20), South Korea and the UK (15), and France (13). In terms of institutional partnerships, the State University of Feira de Santana stands out with 18 joint publications with Portuguese researchers, as does the Federal University of Piauí (UFPI) with 15 collaborative works involving Indian researchers. Figure 6 illustrates the intensity of collaboration between countries and Brazilian institutions in smart city research, based on the articles selected in this study.

RQ4: Scenarios for the application of ICT in smart cities

To better present the density of studies by application scenario, according to the dimensions of the standard ABNT NBR ISO 37122 [2020] and in relation to the topics identified during the classification stage, as described in Section 5.3, Table 4 was organised. The columns of the table contain the ten topics related to the field of ICTs, while the rows represent the 19 application scenarios corresponding to the indicator groups defined by the ABNT NBR ISO 37122 standard. An additional scenario was included to represent cross-cutting studies, which account for the majority of works (33.2%), followed by transport (21.2%), governance (9.7%), and safety (9.7%).

Regarding the topics related to ICT, the highest concentration of research is observed in the area of Data Management (17.3%), while the lowest concentration is found in User Experience and Interface (3.7%). The strongest intersections (excluding cross-cutting scenarios) occur in studies on Artificial and Computational Intelligence within transport scenarios, as well as Data Management, also within transport scenarios, each representing 4.4% and 4.3%, respectively, of the total number of studies considered in this research.

RQ5: Brazilian authors

To identify the researchers who stand out in smart city research, the ten authors with the highest participation were identified, whose output accounts for 25.6% of the articles. Table 5 presents their names, affiliations, and the predominant topics of their publications. Notably, researchers from the Federal University of Rio Grande do Norte (UFRN) are well represented, with five names on the list. In addition, researchers Joel José Puga Coelho Rodrigues and Victor Hugo Costa de Albuquerque stand out as co-authors of three of the four most cited works, as shown in Table 6.

Table 6 contains references to the four studies involving Brazilian authors with the highest number of citations, according to Scopus, Web of Science, and Google Scholar indices. These include two articles published in journals and two papers published in conference proceedings. Vora *et al*. [2018] propose a Blockchain-based framework for storing and maintaining electronic health records (EHRs). The article by Cervantes *et al*. [2015] presents an intrusion detection system designed to prevent sinkhole attacks in IoT device routing services. Khan *et al*. [2019] introduce an energy-efficient system based on deep convolutional neural networks for early smoke detection in IoT environments, using a fog computing architecture. The article by Pardini *et al*. [2020] offers a computational solution to optimise solid waste management, incorporating citizen participation.

RQ6: Publishing Forums

Related to the main forums for disseminating research on smart cities involving information technology topics, 298 distinct venues were identified, of which approximately 59% were conferences and 41% journals. Among the journals, the journal Sensors, published by the Swiss publisher MDPI,

[11] `https://app.vosviewer.com/?json=https://raw.githubusercontent.com/gca-research-group/isys-2026-smart-city/refs/heads/main/VOSviewer/iSys.json`

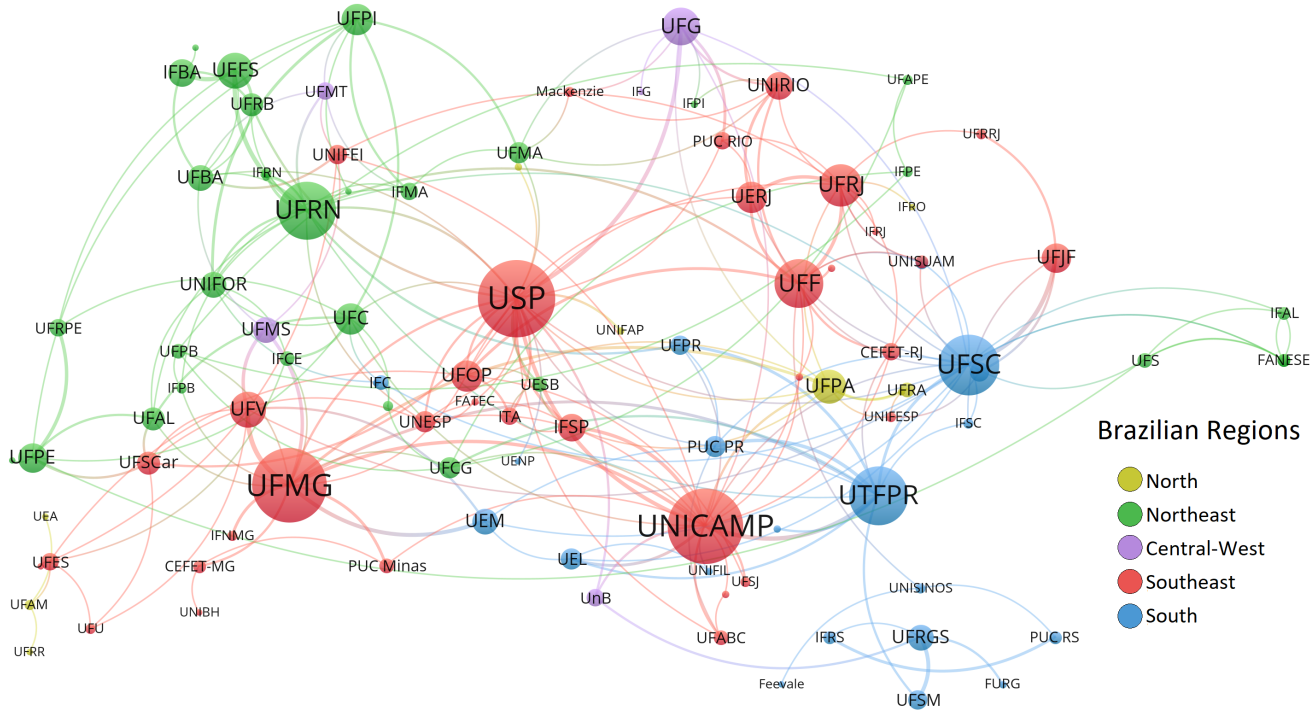

Figure 5. Network of Brazilian Institutions.

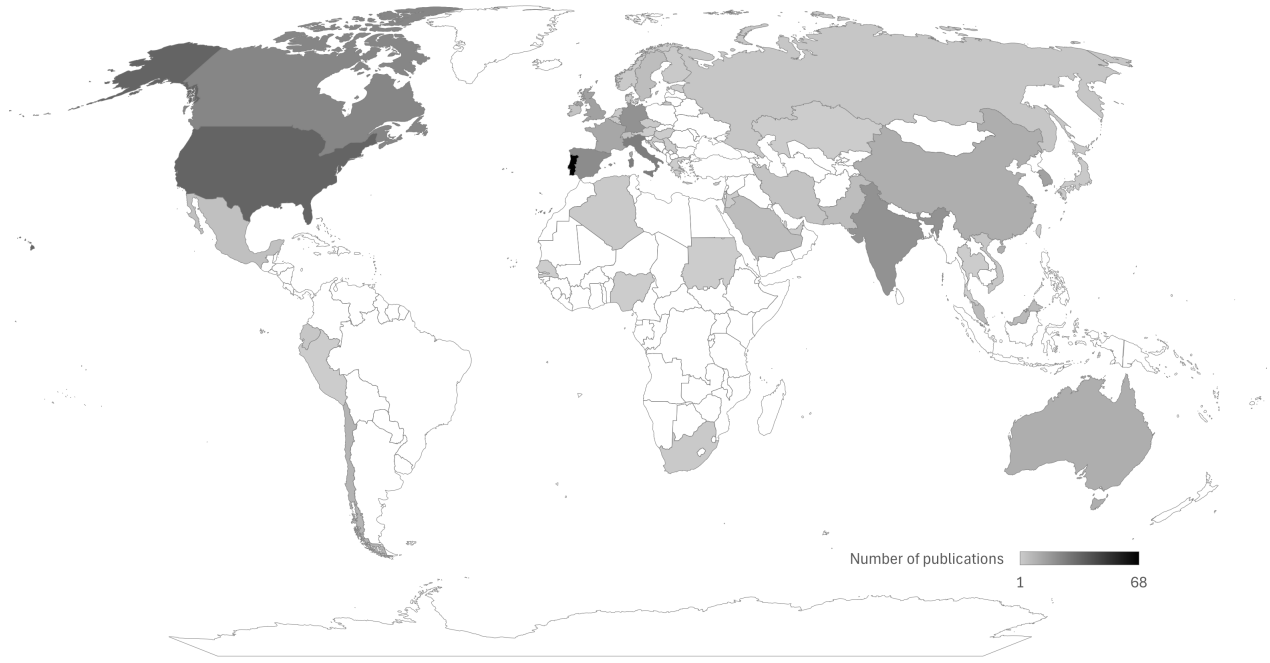

Figure 6. Intensity of international collaboration in selected articles.

Table 4. Number of publications by application scenario (rows) and topic (columns).

	Artificial and Computational Intelligence	Computing Architectures, Infrastructures and Platforms	Data Management	IoT and Ubiquitous Computing	Networks and Communication	Security and Privacy	Sensing and Devices	Software Engineering and Systems Development	Standards, Models and Governance	User Experience and Interface	Total
1) Economy	2		3						1		6
2) Education	1	1		1	1			3	2		9
3) Energy	2	6	7	3	5		7	1	4	1	36
4) Environment and Climate Change	5		3	1	2		6		1		18
5) Finance									1		1
6) Governance	1	2	20			2	3	5	21	8	62
7) Health	3	5	5	3		3	5	1	1	1	27
8) Housing				3	1		1				5
9) Population and Social Conditions	2	1	3	6			2		1	4	19
10) Recreation		1			2					1	4
11) Safety	23	6	12	6	2	1	4	5	1	2	62
12) Solid Waste	2	5		1	3	1	2				15
13) Culture and Sports	1										1
14) Telecommunications	8	2	3	3	20	10	8	1	3		58
15) Transportation	31	8	30	9	11	4	16	17	6	4	136
16) Urban/Local Agriculture and Food Security	2		1				1				4
17) Urban Planning	3	1	5		1		1	3	3		17
18) Wastewater							1				1
19) Water	4	1		1			2				8
20) Cross-Cutting	12	59	19	20	31	23	16	20	10	3	213
Total	**103**	**98**	**111**	**57**	**79**	**45**	**74**	**56**	**55**	**24**	**702**

Table 5. Number of publications per brazilian researcher (Top 10).

Researcher	Filiation	Predominant Topic	J[a]	C[b]	∑
CACHO, Nélio	UFRN	Computing Arch., Infrastruct. and Platforms (12)	5	25	30
RODRIGUES, Joel	SENAC	Networks and Communication (9)	14	10	24
LOUREIRO, Antonio	UFMG	Networks and Communication (6)	10	9	19
LOPES, Frederico	UFRN	Computing Arch., Infrastruct. and Platforms (8)	3	16	19
COSTA, Daniel	UEFS †	Sensing and Devices (10)	9	9	18
BATISTA, Thais	UFRN	Computing Arch., Infrastruct. and Platforms (9)	3	12	15
ALBUQUERQUE, Victor	UFC	Artificial and Computational Intelligence (7)	13	1	14
IANO, Yuzo	Unicamp	Standards, Models and Governance (4)	13	1	14
SILVA, Ivanovitch	UFRN	Artificial and Computational Intelligence (5)	5	9	14
CAVALCANTE, Everton	UFRN	Computing Arch., Infrastruct. and Platforms (7)	2	11	13

[a] Number of published papers in **J**ournals
[b] Number of published papers in **C**onferences
† Since 2022, researcher COSTA, Daniel is affiliated with the University of Porto (Portugal)

Table 6. Most cited papers.

Reference	Publication type	Application Scenario	Scopus [a]	WoS [b]	GS [c]
Vora *et al*. [2018]	Conference	Health	274	171	412
Cervantes *et al*. [2015]	Conference	Cross-cut	218	167	343
Pardini *et al*. [2020]	Journal	Solid Waste	191	130	316
Khan *et al*. [2019]	Journal	Safety	182	161	224

[a] Nº. of citation on https://scopus.com/
[b] Nº. of citation on https://www.webofscience.com/
[c] Nº. of citation on https://scholar.google.com/

stands out, with 26 selected articles included in this study. Table 7 presents the ten journals with the highest number of publications, along with quality indicators such as JCR (Journal Citation Reports) and SJR (SCImago Journal Rank), which measure the impact and reach of these journals. With respect to conference publications, Table 8 identifies the six events with the highest number of publications involving Brazilian authors. Notable among these are national events such as the Brazilian Symposium on Computing Systems Engineering (SBESC) and the Brazilian Symposium on Information Systems (SBSI), as well as the IEEE Summer School on Smart Cities, whose only edition took place in Natal (RN) in 2017. The column named "%" refers to the percentage relative to the total number of conference-type publications.

It is worth highlighting the role of the Brazilian Symposium on Information Systems (SBSI) as the most prominent Brazilian forum in terms of the number of publications on smart cities from the perspective of ICT. Articles were identified in the 2016 (2), 2018 (2), 2019 (1), 2023 (3), and 2024 (1) editions, covering various application domains such as governance, health, education, transport, population and social conditions, energy, and safety. The predominant topic among these publications is artificial intelligence (4), although other topics are also addressed, including data management, standards, models and governance, sensing and devices, and ubiquitous computing and IoT. SBSI has increasingly established itself as an important venue for discussion on smart cities in Brazil.

5.5 Threats to validity

This section identifies potential threats that could compromise the results of this study and details the actions taken to mitigate them. To minimise threats to construct validity, we opted for the use of a sufficiently broad term ("smart city"), including its plural and Portuguese-language variations, in order to encompass publications directly related to the study's topic. Furthermore, the research questions were structured to elicit highly objective responses, enabling the mapping and categorisation of the selected studies. Regarding the classification categories used during the analysis stage, we chose to adopt at least one internationally recognised and standardised classification, in this case, the ABNT NBR ISO 37122 standard.

To mitigate threats to internal validity, we sought to define clear inclusion and exclusion criteria, recording for each article the reasons for its retention or exclusion from the study. Furthermore, the classification stage was conducted in two rounds, allowing the revisiting of studies for improved categorisation when necessary. Regarding external threats, we chose to define a time period longer than a decade (2014-2025), aiming to capture the greatest possible representativeness of smart city research in Brazil. In addition, the use of multiple well-established databases related to the study's area of interest further minimised external threats. Potential threats to reliability were mitigated through the adoption of a standardised and recognised guideline, with all protocol details explicitly documented throughout the study, for example, the search string and the inclusion/exclusion criteria.

6 Discussions

The discussion begins by examining the temporal evolution of the studies. A progressive consolidation of this research field is evident between 2014 and 2018, as reflected in the increasing volume of academic publications. During this period, scholarly output was predominantly disseminated through

Table 7. Number of publications per journal (Top 10).

Journal	Country	1st Ed.	JCR [a]	SJR [b]	HI [c]	†Nº.
Sensors	Switzerland	2001	3.5	0.764	273	26
IEEE Access	USA	2013	3.6	0.849	290	17
Lecture Notes in Computer Science	Germany	1973	-	0.352	499	15
Smart Innovation, Systems and Technologies	Germany	2010	-	0.163	39	13
IEEE Internet of Things Journal	USA	2014	8.9	2.483	208	13
Future Generation Computer Systems	Netherlands	1984	6.1	1.551	180	13
Communications in Computer and Information Science	Germany	2007	-	0.182	75	12
Journal of Internet Services and Applications	Brazil	2010	0.9	0.406	34	9
Lecture Notes in Networks and Systems	Switzerland	2016	-	0.166	48	8
Smart Cities	Switzerland	2018	5.5	1.398	42	7

[a] Impact Factor | `https://jcr.clarivate.com/jcr-jp/`
[b] Scimago Journal & Country Rank | `https://www.scimagojr.com/`
[c] H-Index computed by Scimago Journal & Country Rank
[†] Number of publications mapped

Table 8. Number of publications per conference (Top 6).

Conference	Nº. Editions	†Nº.	%
IEEE International Smart Cities Conference	12 (2026)	46	11.9%
IEEE Summer School on Smart Cities	1 (2017)	19	4.9%
IEEE Symposium on Computers and Communication	31 (2026)	16	4.2%
Brazilian Symposium on Information Systems	22 (2026)	9	2.3%
Brazilian Symposium on Computing Systems Engineering	16 (2026)	8	2.1%
International Conference on Enterprise Information Systems	28 (2026)	8	2.1%

[†] Number of publications mapped

conference proceedings rather than journal articles, a pattern that suggests a phase of gradual maturation and exploratory development of the topic.

Concurrently, Brazil hosted two major international sporting mega-events (the 2014 FIFA World Cup and the 2016 Olympic Games) which exerted a significant influence on the urban dynamics of 12 Brazilian state capitals, including the country's ten most populous cities. The investments mobilised by these events contributed positively to research activities and to the design and implementation of solutions in urban contexts, with particular emphasis on issues of urban mobility.

The maturity of the field has been gradually achieved since 2018, with a noticeable stabilisation in the number of publications from 2019 onwards, and a more balanced distribution across different types of publications. This maturity stems from the growing interest of the Brazilian government through initiatives aimed at promoting and regulating smart cities. The Brazilian Letter for Smart Cities [BRASIL, Ministry of Regional Development, 2020], issued by the executive branch, and the strategic study published by the Chamber of Deputies [Júnior *et al*., 2021], illustrate this concern. These documents suggest, based on collective reflections, the economic and social reorganisation of the urban environment, which concentrates the majority of the Brazilian population.

With regard to the national research network, regionalised collaborations can be identified, particularly in the more densely populated regions such as the Southeast, Northeast, and South, where there is a predominance of cross-cutting research whose results apply to various urban scenarios. Research in the domain of smart cities tends to reflect the realities and challenges of their respective regional contexts. In the North Region, which has the lowest population density in Brazil, research is predominantly focused on telecommunications. A similar situation is observed in studies conducted by institutions in the state of Bahia, which, according to Brazilian Forum on Public Security [2025], has the second highest rate of intentional mortality; here, research is primarily concentrated on safety-related scenarios. Issues within the transport domain, particularly urban mobility, are more frequently addressed in studies from institutions such as the University of Campinas (UNICAMP), the University of Brasília (UnB), and the Federal University of Technology – Paraná (UTFPR), all located in metropolitan regions with vehicle fleets among the ten largest in the country, as reported by BRASIL, Ministry of Transport [2025].

Municipalities such as Natal (RN, Northeast Region), Curitiba (PR, South Region), and the cities of Rio de Janeiro and Niterói (Southeast Region) are the most frequently mentioned in the studies included in this research. An analysis of the research network based in these municipalities highlights the role of local institutions in fostering smart city initiatives. Particularly noteworthy is the Federal University of Rio Grande do Norte (UFRN), based in Natal, which, through the Digital Metropolis Institute (IMD) [12], has been promoting research in the field of ICT, integrating both public and private initiatives. Among the ten Brazilian researchers with the highest number of publications on smart cities, half are affiliated with IMD. A similar situation is observed with institutions located in the metropolitan regions of Curitiba and Rio de Janeiro, which are municipalities that alternated between first and second place in the 2023 and 2024 editions of the Connected Smart

[12] `https://www.metropoledigital.ufrn.br/`

Cities Ranking [13], based on scores obtained in the Information Technology dimension.

With respect to international collaboration, we identified co-authored publications involving 53 countries. Portugal accounted for the highest proportion of participating authors (9.7%), followed by the United States (5%), Italy (3.8%), Canada (3.4%), and Spain (3.1%); India and Germany each contributed 2.8%. In this context, we highlight institutions such as the University of Campinas (UNICAMP), whose collaboration network encompasses 20 countries, with particularly strong links to Canada and Portugal. We also emphasise institutions such as the Federal University of Piauí (UFPI), the University of Fortaleza (UNIFOR), and the Federal University of Ceará (UFC), which exhibit predominant collaborative ties with Asian countries, notably India, South Korea, and China. Furthermore, the State University of Rio de Janeiro (UERJ) and the Federal University of Rio Grande do Norte (UFRN) maintain collaborations with 10 countries each. UERJ's partnerships are concentrated in Germany, the United States, and Spain, whereas UFRN primarily collaborates with Portugal, the United Kingdom, and Germany. It is important to note that this study also indicates that Brazilian scientific collaboration with South American and African countries is virtually absent. At the continental level, there are only a few exceptions, involving countries such as Chile, Ecuador, and Peru, the latter being the only one that shares a land border with Brazil.

Among the most influential researchers in the field, Joel José Puga Coelho Rodrigues (IFPI, UNIFOR, SENAC-CE) and Victor Hugo Costa de Albuquerque (UNIFOR, UFC) are particularly noteworthy. Both appear in the 11th edition of the ranking "Best Computer Science Scientists in Brazil" [14], published at the end of 2024, occupying the first and second positions, respectively. The mapping conducted in this study indicates that a substantial portion of the diversity of countries collaborating with institutions associated with these researchers is directly related to their high volume of international publications. Furthermore, the analysis reveals that among the four most cited publications in the corpus, three include these two researchers as co-authors. Antonio Alfredo Ferreira Loureiro, from the Federal University of Minas Gerais (UFMG), also appears in the ranking, within the top ten positions. Collectively, these results corroborate the characterisation of ICT-based smart city solutions as an emerging research topic that has attracted considerable attention from leading Brazilian scholars.

Regarding the forums for disseminating research findings, this systematic mapping identified a broad spectrum of venues, encompassing both scientific journals and conference proceedings. The analysis of journals with more than five occurrences revealed a predominance of forms specialising in computer science, as well as venues thematically aligned with smart cities, including those focused on sensors, the internet of things, and computer networks, in addition to journals dedicated to innovation and emerging technologies.

Among the ten journals with the highest number of included publications, nine are published by major international publishers, specifically MDPI (2), IEEE (2), Springer Nature (4), and Elsevier (1). The remaining journal, the Journal of Internet Services and Applications (JISA), is published by the Brazilian Computer Society (SBC) in cooperation with the Brazilian Internet Steering Committee (CGI.br) and the National Laboratory for Computer Networks (LARC).

The event with the highest number of publications identified in this study is the "IEEE International Smart Cities Conference", whose first edition took place in 2015 in China and has not yet been held in Brazil. Following this is the "IEEE Summer School on Smart Cities", which had its only edition in Natal (RN) in 2017, as well as the traditional "IEEE Symposium on Computers and Communication", which has provided an annual platform for discussing emerging topics since 1995, with its 2018 edition hosted in Natal (RN), Brazil. National events such as the "Brazilian Symposium on Information Systems" and the "Brazilian Symposium on Computer Systems" are also among the events with the highest concentration of papers mapped in this study. It is important to highlight the case of the municipality of Natal [Cacho *et al.*, 2016], which, through decentralised initiatives and the gradual implementation of strategic projects, has been building a digital transformation agenda, including the organisation of events focused on smart city solutions.

6.1 Results from a Sociotechnical Perspective

A broader interpretation of the findings, in the light of Sociotechnical Theory, allows us to understand the smart city as a living ecosystem in which technology and society mutually shape one another, rather than merely as an urban project supported by digital technologies. This perspective is reinforced by the observation that Brazilian research on smart cities not only expands in volume but also progressively aligns with the fundamental perspectives of Information Systems (IS). The concentration of studies in transversal domains and multi-organisational contexts reflects the central premise of Sociotechnical Theory, namely that technological artefacts alone do not generate intelligence, since this emerges from the interaction between technical infrastructures and social, institutional, and governance arrangements. As highlighted in the introduction, [Sawyer and Jarrahi, 2014] emphasise that sociotechnical systems require the coordinated evolution of both technological and human subsystems.

In the context of smart cities, the adoption of technological artefacts such as IoT devices or digital platforms must equally take into account the social and organisational factors that influence their use, including the involvement and engagement of citizens, public managers, and companies. In this regard, the study's data, relating to ICT categories, highlight two important gaps: the limited number of studies addressing user interfaces and experiences, as well as those focusing on security and privacy. The first gap underscores the fact that, without end-user adoption, the smart city will not achieve effectiveness. Similarly, the issue of privacy and security reveals another bottleneck: trust. From a practical perspective, the smart city can be understood as a "Systems of Systems", characterised by strong technological integration and the circulation of vast amounts of data, including sensitive information. This demonstrates that, without solid technical guarantees of

[13] https://ranking.connectedsmartcities.com.br/

[14] https://research.com/scientists-rankings/computer-science/br

security and anonymisation, there is a risk of silent boycott by the human component, which is a key element for the success of a sociotechnical system. This tendency is consistent with the challenges identified in [Neto and Frantz, 2025], who argue that smart cities exemplify complex environments of multi-organisational information systems that demand new paradigms of integration.

Moreover, the temporal evolution of publications and the growing presence of articles in journals indicate a maturation of the field, aligned with the Systems of Systems perspective adopted by the Brazilian Computer Society. Smart cities, as discussed by [Bernardini *et al.*, 2017], require architectures capable of coordinating autonomous subsystems while maintaining global coherence. The mapping results show that Brazilian research increasingly explores distributed architectures (for example, IoT, sensing platforms, and the edge–fog–cloud computing continuum), which are emblematic of the principles of Systems of Systems, such as decentralisation, emergent behaviour, and adaptive coordination. This suggests a gradual migration of national research from isolated technological solutions towards more integrated IS structures, capable of sustaining large-scale urban ecosystems.

Finally, the observed patterns of international collaboration reflect the globalisation of IS research and the dissemination of digital transformation agendas. These collaborations can be interpreted through the lens of the dynamics of innovation diffusion in IS, in which the flow of knowledge across institutional and national boundaries accelerates the adoption of new technological paradigms. In this respect, it is also important to consider the absence of international collaboration between Brazil and its South American neighbours, as well as with countries on the African continent. It is understandable that the high number of publications in partnership with institutions in Portugal is related to historical and linguistic ties. Similarly, collaborations with other European countries and North America can be explained by the development and transfer of technology fostered by international collaboration networks and joint degree agreements, which have historically been more consolidated with these nations. On the other hand, in the context of the Global South, Brazil is a continental country that shares social inequalities, infrastructure bottlenecks, and climate challenges very similar to those of South American and African countries. The North American, European, or Asian smart city model is undoubtedly more distant from the Brazilian reality when compared to that of its neighbours, who have also faced intense and recent unplanned population densification. In this respect, the study highlights opportunities for the future expansion of Brazil's role as a regional hub of innovation in smart cities driven by IS. This finding underscores the importance of cooperation agreements and joint funding calls that promote collaboration among institutions in the Global South, beginning with the members of Mercosur.

Taken together, these theoretical connections indicate that Brazilian research on smart cities not only expands empirically but also increasingly consolidates itself within the conceptual foundations of Information Systems. This reinforces the relevance of ICT-based approaches for addressing sociotechnical, organisational, and infrastructural challenges in the national urban context, while at the same time revealing theoretical gaps—such as governance, citizen participation, and institutional integration—that future studies may explore in a more systematic manner.

6.2 Practical and Theoretical Implications for Ecosystem Actors

Together, the empirical findings and the theoretical deepening of this mapping generate direct and actionable implications for four fundamental groups involved in smart city initiatives:

Implications for Researchers in Information Systems

- **Paradigmatic Transition from Technology-Push to Joint Optimisation**: Information Systems researchers should broaden their agendas beyond purely algorithmic development (such as Artificial Intelligence and Data Management), incorporating the social dimension as a primary variable of investigation. There is an urgent need for empirical studies focused on User Experience (UX/UI), cognitive usability in public interfaces, and citizen co-design methods.
- **Scientific Advancement in Systems of Systems Engineering and Integration Testing**: Given the predominance of transversal scenarios, the scientific community should prioritise the development of rigorous methodologies for software testing in Systems of Systems environments, including simulations with Digital Twins and semantic interoperability frameworks that ensure the operational autonomy of applications.
- **Addressing Privacy Gaps**: The deficit of research in security and privacy requires IS scholars to investigate privacy-oriented architectures from the design stage (privacy-by-design), solutions based on Personal Data Stores (PDS), and adaptive real-time anonymisation techniques for IoT ecosystems.
- **Diversification of International Cooperation (South–South Networks)**: A reorientation of academic partnerships is recommended, with the establishment of formal research networks with institutions in Latin America and on the African continent. The aim is to build IS theories informed by the specific socio-economic and institutional contingencies of the Global South.

Implications for Policymakers

- **Reorientation of R&D Funding Calls and Programmes**: Government research funding agencies should rebalance their investments, directing specific credit lines towards urban IT projects that require sociotechnical validation, citizen participation, and social impact assessment. This reorientation is necessary to overcome the exclusive emphasis on hardware and physical infrastructure, promoting initiatives that integrate technological and social dimensions.
- **Regulation and Standardisation of Data Interoperability**: Policymakers should establish regulatory frameworks and national guidelines for urban data, grounded in open architectures and standards (e.g., ABNT NBR ISO 37122). Adherence to interoperability standards and to the General Data Protection Law (LGPD) must be mandatory as a prerequisite for public procurement

of smart solutions, ensuring legal security and technical consistency.

- **Incentives for Reducing Regional Asymmetries**: It is essential to create public policies aimed at digital transformation and scientific research, with a specific focus on the North and Centre-West regions. These measures should ensure digital inclusion and connectivity in areas of lower population density and high logistical vulnerability, contributing to the reduction of regional inequalities and to the consolidation of more balanced urban development.

Implications for Public Organisations and Municipal Managers

- **Adoption of the Systems of Systems Paradigm in Place of Technological Silos**: Municipal governments and departments should avoid contracting proprietary and monolithic platforms. It is recommended that open ecosystem architectures be adopted, enabling continuous and multi-organisational integration across sectors such as transport, energy, health, and public safety, while simultaneously preserving the operational autonomy of each agency.
- **Building Citizen Trust through Technical Privacy Guarantees**: To address the so-called "Privacy Paradox", public administrations should incorporate explicit data protection safeguards into their urban service portals and applications. Transparent demonstration of compliance with the General Data Protection Law (LGPD) and the systematic use of anonymised data constitute fundamental conditions for encouraging the sharing of information by citizens and private organisations.
- **Institutionalisation of Multidisciplinary Sociotechnical Teams**: City halls and urban control centres should restructure their technical staff by establishing permanent committees composed of computer scientists, software engineers, public managers, urban planners, and sociologists. These committees should guide the specification, implementation, and monitoring of municipal systems, ensuring that technological solutions are aligned with social and institutional needs.

Implications for Engineers & System Integrators

- **Citizen-Centred Design and Interface Ergonomics**: Software engineers and digital product designers should prioritise user experience (UX/UI) and usability in public urban systems, in order to minimise adoption barriers and prevent the emergence of informal and undocumented routines (workarounds) by public servants and citizens.
- **Adoption of Middlewares and Open Protocols**: Developers of smart platforms should adopt standardised middlewares and open APIs that enable the dynamic orchestration of data from multiple IoT sensors and mobile devices. This practice is essential to ensure the scalability of solutions in cloud and fog computing environments.
- **Integrated Security and Data Protection by Design**: Technology industry professionals should incorporate rigorous cybersecurity protocols from the initial requirements-gathering phase. This includes resilience mechanisms for mobile networks and protection against cryptographic vulnerabilities, ensuring technical compliance in multi-organisational contexts and strengthening trust in the products developed.

7 Conclusions and future work

Urban densification driven by rapid population growth poses a range of complex challenges for municipal administrators. According to Sowmiya and Velavan [2025], smart city initiatives employ information and communication technologies (ICTs) to enhance the provision of public services, optimise the management and operation of urban infrastructure, and foster transparency in decision-making processes, thereby aligning with global sustainability agendas. In this article, we report a systematic mapping study designed to provide a comprehensive overview of the adoption of ICT in Brazilian smart city research. From an initial corpus of 1,129 unique documents retrieved through searches in reputable ICT-focused scientific databases, 702 documents (62%) were selected for classification, following the systematic protocol specified in the guidelines of Kitchenham and Charters [2007] and Petersen *et al*. [2015].

The results obtained in this study provide a consolidated and up-to-date overview of Brazilian research on smart cities, with a focus on ICT. This has enabled the identification of key urban scenarios and thematic areas where research problems are concentrated, as well as relevant gaps. In addition, the study maps the national research network, its international collaborations, and the most prominent researchers in the field. Systematic mapping studies offer a comprehensive overview of the state of the art in a given research area and allow the identification of opportunities for future investigations. In this regard, the results highlighted that crucial aspects for the effectiveness of digital urban ecosystems, such as user experience and interfaces as well as information privacy and security, remain underexplored. In the Brazilian context, these gaps assume particular relevance given the persistent challenges related to urban infrastructure and suggest that such themes should receive greater attention in the strategic research agenda on smart cities. Furthermore, the practical implications identified reinforce the need to strengthen and reorient public policies, funding programmes, and scientific cooperation networks, in order to reduce regional asymmetries and contribute to positioning Brazil as a hub of innovation in sustainable urban solutions.

As future work, we intend to deepen the analysis of more specific topics within ICTs that have emerged as promising and represent research gaps in the context of smart cities. Furthermore, we intend to conduct a symmetric mapping study, applying the same protocol in another South American country, most likely Colombia, with which we maintain robust research collaboration, and we have observed that research on smart cities is becoming a trend, as well as in European countries such as Portugal and Spain, which, in general, exhibit strong collaborative ties with Brazilian research groups.

Declarations

Authors' contributions

RZF contributed to the conception of this study. BBB executed the methodological protocol and is the lead author of this manuscript. RZF reviewed the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets generated and analysed during the current study are available in `https://github.com/gca-research-group/isys-2026-smart-city`.

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