Smart City Technologies: Challenges and Opportunities for Salvador-Bahia, Brazil

Arthur Farias da Silva Santos[1] Cauã Leahy Daltro[1]; João Lessa Ribeiro Neto[1]; Laura Bárbara Brito Cunha Lima[1]; Lucas Santos Lima[1]; Matheus Ribeiro de Sena[1]; Samara Souza Pinto[1]; Rosana Vieira Albuquerque[2]*, Morjane Armstrong Santos de Miranda[3]

[1] *Universidade SENAI CIMATEC, undergraduate in computer engineering, Salvador, Bahia;*
[2] *Universidade SENAI CIMATEC; SENAI Innovation Institute for Logistics; Salvador, Bahia;*
[3] *Universidade SENAI CIMATEC; Researcher Trail; Salvador, Bahia;*
* *University Senai Cimatec; Av. Orlando Gomes, 1845 - Piatã, Salvador - BA, 41650-010;*
arthur.f.santos@aln.senaicimatec.edu.br; rosanavieiraalbuquerque@gmail.com

Abstract: This study centers on the city of Salvador as it transitions toward becoming a smart city. It examines its main challenges: sanitation, pollution, and social inequalities, and compares these with established smart-city models. The study also presents example technologies, including the Internet of Things (IoT), artificial intelligence (AI), and cybersecurity, and outlines pathways for their application to tackle key urban problems. Conducted at a pivotal moment in Brazilian urban development, when cities face complex challenges related to governance, infrastructure, and social inclusion, the research aims to identify Salvador's priority issues and the smart-city technologies that can be applied to address them, along with the expected impacts on Sustainable Development Goals (SDG) 9 and 11 in Salvador.

Keywords: smart cities. Salvador. Brazil. smart-city technologies. intelligent cities.

1. Introduction

A smart city is a contemporary phenomenon that delivers social, economic, and environmental sustainability outcomes and responds to challenges such as climate change, population growth, and political and economic instability. From a broad perspective, a smart city seeks to bring together the environment, technological innovation, and human development to provide more efficient services to society. It is important to note that a smart city is not limited to the deployment of emerging and innovative information and communication technologies (**ICTs**). Tironi (2013) [16] explains that, to be characterized as such, the city must adhere to sustainable urban development (smart environment), incorporate information and communication technologies into the management of services (smart economy), generate participatory spaces for collaboration and innovation (smart governance), and cultivate responsible citizens (smart citizen).

The promotion of technologies that drive the development of smart cities is directly related to Sustainable Development Goal 9 (**SDG 9**) established by the United Nations, which aims to "build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation," according to the Institute for Applied Economic Research (**IPEA**) [6]. In this way, smart cities play a fundamental role by integrating advanced technologies into urban management, resulting in more efficient and sustainable infrastructure.

The Connected Smart Cities Ranking is an initiative by Urban Systems that maps and compiles indicators of Brazilian cities' development with respect to the aspects of a smart city. Based on these collected data,

Brazilian cities were ranked by level of development, as shown in the following Table 1.

Rank	City - State	Rank	City - State
1°	Florianópolis - SC	6°	Balneário Camboriú - SC
2°	Vitória - ES	7°	São Caetano do Sul - SP
3°	São Paulo - SP	8°	Belo Horizonte - MG
4°	Curitiba - PR	9°	Barueri - SP
5°	Niterói - RJ	10°	Salvador - BA

Table 1. Connected Smart Cities Ranking

Source: Prepared by the authors (2025), adapted from the Connected Smart Cities Ranking (2024, p. 21). Over the years, Salvador has gained increasing prominence. According to the Municipal Secretariat of Innovation and Technology (SEMIT) [9], in 2024 the city placed first among Northeastern capitals and tenth overall in the national ranking of the 100 smartest cities. In this smart-city context, Salvador stands out as the first Brazilian municipality to develop a Smart City Technology Master Plan (**PDTCI**). Prepared by the SEMIT, it is among the pioneers among Brazilian capitals in adopting international smart city standards. The PDTCI is aligned with standards issued by the International Organization for Standardization (**ISO**) and was recently incorporated by the Brazilian Association of Technical Standards (**ABNT**). Salvador thus assumes a leading role by investing significantly in the transition to an integrated model of urban management, with substantial financial resources allocated both to the planning phase and to the implementation of the required technological solutions.

Although Salvador is one of Brazil's largest capitals, it faces challenges in several areas, including public security, housing, sanitation, and mobility, among others. A clear example is the situation of communities located in high-risk areas, where the lack of adequate infrastructure exacerbates existing social hardships. This underscores the need to invest in technologies that can help address these urban social problems.

In the current scenario, the application of emerging technologies is crucial, since they can make Salvador a smarter city and provide residents with a better quality of life.

This research is set at a critical moment in Brazilian urban development, when cities face complex challenges related to governance, infrastructure, and social inclusion. Against this backdrop, the guiding research question is: What are Salvador's main challenges, and which smart-city technologies are applicable?

Understanding how the component technologies of a smart city can be applied is essential for improving public services, since the use of ICTs enables the mitigation of urban problems and supports a better quality of life for the population. Accordingly, the study's overarching objective is to identify Salvador's principal challenges and the smart-city technologies that can be applied to address them, along with the expected contributions to SDG 9 and SDG 11. The specific

choice of Salvador as the focus is grounded in its strategic positioning: the city has already advanced studies and municipal planning that include significant investments, with R$ 4.5 million allocated to the initial planning phase and R$ 60 million projected for implementation.

2. Theoretical Framework

2.1 Smart Cities

According to **MDR** (2021) [15], "smart cities" are those committed to sustainable urban development and digital transformation—across their economic, environmental, and sociocultural dimensions—that act in a planned, innovative, inclusive, and networked manner, promoting digital literacy as well as collaborative governance and management. In addition, they make use of technologies to solve concrete problems, create opportunities, deliver services efficiently, reduce inequalities, increase resilience, and improve the quality of life for all people, ensuring the safe and responsible use of data and information and communication technologies (**ICTs**).

The 17 Sustainable Development Goals (**SDGs**), which form part of the 2030 Agenda launched by the United Nations, aim to tackle the world's major challenges. Among these goals, SDG 9 (Industry, Innovation and Infrastructure), which seeks to promote resilient infrastructure, sustainable industrialization, and innovation, has a strong connection with the concept of smart cities by encouraging the strategic use of innovative technologies and intelligent infrastructure to address diverse needs.

There is also a connection with SDG 11 (which specifically concerns Sustainable Cities and Communities) and it seeks to make urban areas inclusive, safe, and resilient by ensuring adequate housing, basic services, and high-quality urban development by 2030. Smart city initiatives directly advance this objective through real-time monitoring, citizen participation, smart waste management, and integrated transportation solutions, strengthening urban sustainability and social equity. In essence, smart cities are urban centers that employ advanced technologies aligned with sustainable practices to enhance citizens' quality of life and significantly reduce environmental impact. In this context, sustainability plays a fundamental role in human development, since, since the Industrial Revolution, issues such as the intensification of the greenhouse effect and the depletion of natural resources have become increasingly urgent challenges (GENARI et al., 2018) [3]. Accordingly as Elkington (1997) [17], states, sustainability is grounded in three perspectives: economic, social, and environmental (profit, people, and planet), also known as the triple bottom line (**TBL**) model, as presented in Frame 1.

Sustentabilidade	Definition	Benefits	Fontes
Environmental	Environmental sustainability focuses on organizations' impacts on	Development of more efficient production systems. Environmentally	(JAMALI, 2006). (GENARI et al., 2018). (PEREIRA, 2009; BAUM-

	ecosystems and goes beyond mere regulatory compliance and recycling efforts.	sound, economically viable practices. Clean technologies.	GARTNER; EBNER, 2010).
Social	Social sustainability aims to ensure equal access to quality goods and services by removing the main sources of social inequality and deprivation of freedom, such as poverty, lack of economic opportunities, and neglect of public services.	Equity in living standards. Equal opportunities. Better working conditions and labor rights.	(MENDES, 2009). (GENARI et al., 2018). (PEREIRA, 2009). (JAMALI, 2006).
Economic	Economic sustainability encompasses formal and informal activities that provide services to individuals and groups, increasing monetary income and raising living standards.	Economic efficiency. Greater human development. Investments across diverse areas of technological development.	(CLARO; CLARO; AMÂNCIO, 2008). (GENARI et al., 2018).

Frame 1 - Triple Bottom Line Model - Sustainability Perspectives.

Source: Prepared by the authors (2025).

2.2 Challenges in the City of Salvador

Salvador ranks tenth among Brazil's smartest cities, and although the goal of smart cities is to promote quality of life and sustainability, the city still faces challenges and statistics that highlight the need for investments that keep pace with technological advances so that the population is effectively served. According to the Sustainable Development of Cities Index – Brazil (**IDSC-BR**) [5], Salvador still faces sustainability-related challenges, with medium performance in good health and well-being and reduced inequalities; low performance in quality education, gender equality, life on land, partnerships for the goals, and peace, justice and strong institutions; and very low performance in decent work and economic growth and in industry, innovation and infrastructure.

According to Bahia's Environmental and Water Resources Institute (**INEMA**) [7], bathing water quality refers to the condition of waters used for primary-contact recreation, meaning direct, prolonged contact where a significant amount of water may be ingested. In Salvador, Bulletin No. 16/2025 reports that 24 of the 38 sampling sites were classified as unsuitable for bathing.

Salvador also has only 39.5% of its public streets lined with trees, and a significant burden of air pollutants, as reported by the Fiocruz News Agency in the article "Air pollution in Salvador: a risk-analysis approach for decision-making": "The study, coordinated by Fiocruz Bahia researcher Nelzair Vianna, detected pollutants such as particulate matter (PM), nitrogen dioxide

(NO_2), and carbon dioxide (CO_2) in the city's air. Specific analyses were carried out to characterize urban atmospheric particulate matter, in which metals such as cadmium, chromium, and lead were detected. These 2.5-micrometer particles ($PM_2.5$) are so fine that they can penetrate deep into the lungs."

Considering the environmental dimension alongside infrastructure, a key component is basic sanitation, which, according to the National Water Agency (**ANA**) [1], comprises water supply; sewage collection and treatment; urban cleaning and the collection and disposal of solid waste; and stormwater drainage and management. In this context, despite standards, oversight, and sanitation agencies, data from the National Sanitation Information System (**SNIS**) [13] indicate that Salvador still has residents without access to basic sanitation services: 1.24% of the population lacks access to water; 3.35% lacks solid-waste collection; 11.66% lacks adequate sewerage; and 0.1% of households are subject to flooding.

Methodology

This basic research, conducted between January and June 2025 with an exploratory–descriptive design and qualitative analysis, aims to expand theoretical knowledge about Salvador's challenges and potential in its transition to a smart city. The study describes urban indicators, public policies, and emerging technologies already adopted, and it explores relationships among these elements that have received little investigation. To guide this design, we adopted the procedures proposed by Gil [4]. In separately defining exploratory and descriptive research, Gil [4] characterizes them as studies whose main purposes are to develop, clarify, and refine concepts and ideas with a view to formulating more precise problem statements or hypotheses to be tested in subsequent studies, and to describe the characteristics of a given population or phenomenon or to establish relationships between variables. He also indicates that planning qualitative procedures involves defining the research objectives from a qualitative perspective, selecting the sample, and collecting and analyzing data (GIL, 2019, pp. 26–27 and 155). As for data, we examined publications (from 2020 onward) in secondary databases such as SciELO and Google Scholar, using the keywords "Smart Cities," "Challenges in the City of Salvador," and "Smart City Technologies." The study also includes a document analysis of technical reports from the Salvador municipal government and municipal legislation

The methodological approach comprised nine sequential steps, as shown in Figure 1.

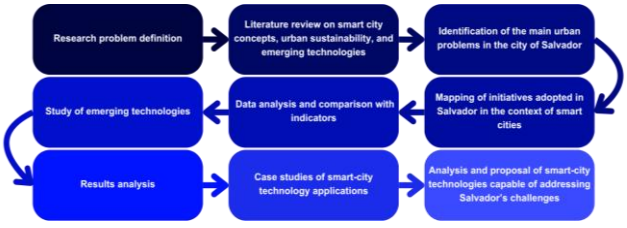

Figure 1. Methodological Steps

Source: Prepared by the authors (2025).

4. Results and Discussion

Below, we concisely examine how three cities applied different tools to address

specificchallenges, yielding measurable gains in energy efficiency, environmental quality, and mobility.

City	Tools	Benefits	Type of sustainability	Technology applied
Helsinki (Finland)	• Offshore wind farms • Biomass plants • Smart public lighting with presence sensors and remote contro	• 27% reduction in CO_2 emissions since 1990 • Progress toward carbon neutrality by 2035 • Operational savings on the power grid through optimized lighting operation	Environmental sustainability	IoT (presence sensors and remote control)
Singapore (Singapore)	Green corridors • Green roofs on public buildings • Linear parks • Rainwater capture and reuse systems	• Up to 2 °C temperature drop in critical neighborhoods (mitigating urban heat islands) • Improved air quality (reduced $PM_{2.5}$ and NO_2) • Fewer respiratory illnesses	Urban sustainability	Data and Artificial Intelligence (environmental monitoring and urban planning)
Zurich (Switzerland)	• Adaptive lighting poles with sensors • Smart traffic lights connected to a real-time control center	• Up to 70% savings in public lighting • Reduced congestion via real-time signal timing adjustments • Lower pollutant emissions due to fewer frequent stops	Energy sustainability	IoT and Artificial Intelligence (dynamic adjustment of lighting and traffic)

Table 2. Smart Cities: Analysis of tool application and benefits achieved. Source: Prepared by the authors (2025), based on SCOOP.MARKET (2024) and EARTH.ORG (2025).

The analysis of Table 2 shows that, although they differ in scope and tools, the three cases adopt complementary solutions based on sensing, automation, and green infrastructure to deliver environmental, economic, and social gains. Helsinki and Zurich invested heavily in smart lighting and traffic-signal systems, equipped with presence, luminance, and motion sensors, to curb energy use and improve traffic flow, whereas Singapore stood out for deploying green corridors, green roofs, and rainwater harvesting, focusing on thermal regulation and air quality. In summary, integrating renewable energy, green infrastructure, and real-time IoT solutions yields a triad of benefits: (i) environmental, through

lower emissions and pollutants; (ii) economic, via optimized operating costs; and (iii) social, by improving health and mobility, providing valuable guidance for Salvador when selecting technologies best suited to its specific challenges.

Type of Sustainability	Challenges in the city of Salvador	Applicable technologies	Expected impacts
Environmental	• Air pollution • Low urban tree cover • Inadequate sanitation	• IoT for environmental monitoring and risk prevention • Big Data for risk and pollution analysis	• Improved air and water quality • Reduced pollution • Increased tree coverage
Social	• Social inequality • Shortfalls in education and public health	• IoT to monitor risk in vulnerable areas • Use of AI to improve the performance of public policies • Cybersecurity to protect population data and public	• Reduced inequalities • Mitigation of problems in vulnerable communities • Improved public services • Greater speed and reliability of
		services	systems
Economic	• Low infrastructure development	• Apply AI to support economic development • Big Data to support service management • Cybersecurity to protect systems	• Improved city infrastructure • Greater speed and reliability of systems

Table 3. Sustainability Challenges in Salvador, Technologies, and Expected Impacts.

Source: Prepared by the authors (2025).

The proposals presented in the preceding Table 3 show that deploying technologies such as cybersecurity, IoT, AI, and big data can significantly help Salvador advance toward the selected SDG. The integration between these tools and the mapped challenges outlines a strategic path for transforming the city into a smart city that meets residents' needs. The use of smart city technologies can move Salvador closer to SDG 9 and SDG 11 by directly contributing to the mitigation of social and structural problems. Big data and AI enable precise diagnostics and can predict failures in systems and infrastructure, in addition to assisting maintenance. IoT allows sensors to provide real-time data, optimizing public management. Cybersecurity protects every technology against cyberattacks as well as

citizens' data and public services. In this way, the initiatives to develop infrastructure and promote industrialization (SDG 9), and the effort to make cities safer and more sustainable (SDG 11), would be supported.

Considering the research results, our analysis of Salvador's PDTCI shows a strong convergence between the technologies identified in our study and those outlined in the municipal plan. Our study highlights IoT, AI, cybersecurity, and big data as key smart-city technologies applicable to Salvador's challenges, and offers an academic and propositional perspective, grounded in international comparisons, that can provide the municipal administration with valuable inputs to evaluate, refine, and expand planned initiatives, as well as to design new long-term actions under the PDTCI. The plan not only mirrors these findings, it also integrates them into its structure, objectives, and supporting infrastructure.

5. Final Considerations

The study identified Salvador's main challenges and examined how emerging technologies, within the smart-city context, could be applied to address them, relating these applications to progress on SDG 9 and SDG 11. It also drew on smart-city case studies from leading cities in international rankings. The central takeaway is the importance of aligning technological innovation with public policies aimed at inclusion and equity, reaffirming that the smart-city concept goes beyond service digitization and requires integrated urban planning, civic participation, and social justice. The research objective was achieved, and through the analysis of Table 3, we showed how each proposed technology can deliver concrete and significant impacts. Moreover, this investigation contributes not only academically, by outlining key challenges and applicable technologies, but also to municipal management by proposing solutions to the city's challenges, which may lead to revisions and improvements in its PDTCI. It can also support other Brazilian cities in advancing based on this study and new applications. This research was limited to four principal smart-city technologies, namely cybersecurity, IoT, AI, and big data, selected for their relevance and applicability to the mapped challenges. However, there are other promising technologies that warrant future exploration, such as blockchain, augmented reality, and robotics, which have the potential to contribute positively to critical areas of urban management. We therefore propose continued studies in this field to assess additional applicable technologies that can help more cities advance on **SDG** 9 and **SDG** 11, as well as on other Sustainable Development Goals.

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