Context-sensitive measurement: Addressing the local context in smart city assessment

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Abstract. Various organizations and researchers have developed Smart Cities Measurements (SCM) to monitor the advance of Smart Cities (SC) initiatives worldwide, yet there is no consensus about their impact on local governments. Local managers implement SC and SCM projects differently depending on their contexts, but few studies have analysed these measurement initiatives from local governments' perspective. To address this gap, this paper aims to identify how municipalities use SCM and adopt indicators according to local context. Data were collected by in-depth semi-structured interviews with representatives from seventeen Brazilian cities, including different regions and population sizes. The results describe how local governments adopt measurement frameworks, expanding the literature on SCM.

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1. Introduction

Smart Cities (SC) initiatives aim to improve people's quality of life by adopting multidimensional strategies and using digital technologies to mitigate various complex urban challenges. In this context, Smart City Measurements (SCM) have been developed to monitor and assess the implementation of such projects. The literature shows the importance of measurement in verifying the advance and progress of SC initiatives (Caird et al., 2016; Fachinelli et al., 2023; Hajek et al., 2022). Besides the ultimate goal of improving the quality of life in cities (Sharifi, 2019), being smarter can attract resources, such as investments and talent (Hajek et al., 2022). Other benefits were listed by Huovila et al. (2019), which include easy language to show the development of SC, transparency for citizens about the benefits provided by SC, and support for government decisions.

However, most SCM frameworks are designed to cover many cities, leading to the lack of context-specific indicators that allow to capture the complexity of SC initiatives (Backhouse, 2020). While SCM aim to measure progress, facilitate comparisons, and guide decision-making for local and national governments, they often fail to account for the diverse contexts, priorities, and challenges of individual cities, imposing universal models instead (Backhouse & Dhaou, 2020; Skargren, 2020). Universal measurements can also pose difficulties in understanding the local context, particularly in countries where the diversity of cities' conditions can lead to different needs and issues. In addition, local governments can also adopt different SC perspectives and dimensions. This variety of frameworks is also true for adopting SCM (Albino et al., 2015).

Besides the lack of context-sensitive indicators in measurement frameworks, an additional gap is the need to understand the use of SCM by local governments, particularly in different contexts (Albino et al., 2015; Hajek et al., 2022). Despite the increasing number of papers focusing on defining SCM (Hajek et al., 2022; Huovila et al., 2019; Sharifi, 2019, 2020), just a few studies analyze smart city indicators from the perspective of local governments and local managers (Caird et al., 2016), showing the need for more studies regarding the usefulness of SCM for cities (Sharifi, 2020).

This paper takes a unique approach by focusing on how local governments adopt and use SCM in their smart city initiatives, which leads to developing an understanding of context-sensitive measurement frameworks. To achieve this objective, data were collected by in-depth semi-structured interviews with representatives from seventeen cities in Brazil, including different regions and population sizes. The respondents were top-level managers involved or in charge of measuring indicators related to SC projects. Brazil was chosen because of the complexity and diversity of conditions among more than 5,500 municipalities, providing a fruitful environment to analyse the inclusion of SCM in monitoring SC initiatives.

The theoretical contribution relies on context-sensitive frameworks for local governments and enhances discussions on SCM and SC (Albino et al., 2015; Hajek et al., 2022; Huovila et al., 2019; Sharifi, 2019, 2020). External indicators can help local governments monitor SC projects, especially with limited resources. However, literature suggests that local managers should critically adopt SCM based on their specific contexts, choosing relevant indicators (Sharifi, 2019). Additionally, this paper can provide insights for local governments and policymakers on effectively utilizing SCM frameworks and selecting appropriate indicators for their SC initiatives.

2. Context-sensitive measurement of Smart Cities

The concept of SC focuses on improving urban quality of life through multidimensional strategies and technologies addressing challenges in areas like the environment, mobility, and housing (Albino et al., 2015; Cunha et al., 2016; Nam & Pardo, 2011). However, the lack of consensus on SC dimensions affects the creation of monitoring frameworks and indicators (Hajek et al., 2022; Sharifi, 2019, 2020).The diversity of concepts has led to multiple interpretations and numerous methods and frameworks to measure and monitor SC (Metwally et al., 2023). In this context, SCM has gained interest among SC scholars and practitioners, with different measurement approaches emerging globally (Sharifi, 2020).

SCM frameworks commonly focus on developing indicators, metrics, or standards for SC, including assessment tools, indexes and rankings (Hajek et al., 2022). Literature has been analysing the existing SCM or defining the best indicators and measurements (Sharifi, 2019), such as Bosch et al. (2017) and Huovila et al. (2019) studies. In addition, there is an increasing recognition of the need for context-specific approaches to SC initiatives, given the diverse cultural, social, political, and technological environments of cities (Albino et al., 2015; Alcaide Muñoz & Rodríguez Bolívar, 2021; Esposito et al., 2021). In this sense, Lopes (2017) and Tomor et al. (2019) emphasize how these contextual factors significantly affect SC governance.

De Oliveira et al. (2024) found that the variety of measurement frameworks reflect these contextual influences and highlight the inadequacy of a single definition for SC. Previous studies also advocate for tailored measurement approaches rather than a universal framework (Angelidou, 2014; Albino et al., 2015; Hajek et al., 2022). However, most SCM initiatives did not consider the local contextual conditions (Backhouse, 2020; Ependi et al., 2022; Patrão et al., 2020; Sharifi, 2019). Backhouse and Dhaou (2020) also highlighted that SCM frameworks reflect the priorities and concerns of their creators (whether individual researchers or organizations) and not necessarily the city's needs, and rarely reflect the nuances of the local context, making complex for cities to adopt them considering their needs and challenges (Backhouse & Dhaou, 2020; Backhouse, 2020; Giffinger et al., 2007; Patrão et al., 2020). In this sense, it is fundamental that cities understand possible applications of measurement frameworks in their realities, including adopted dimensions, purposes of measurement, and how the indicators' results impact their goals (Backhouse, 2020).

One way to guarantee the local context is to include context-sensitive indicators aligned with local goals, enabling governments to tailor their actions based on specific needs (Backhouse, 2020; Sharifi, 2019, 2020). However, there is no consensus on defining these indicators. Although many studies have highlighted the importance of context and specific conditions, they do not specify the meaning of context sensitivity or factors that contribute to contextualizing SC indicators (Fernandez-Anez et al., 2020; Hajek et al., 2022; Huovila et al., 2019; Patrão et al., 2020). An exception is Lai and Cole (2023), who argue SCM should measure and compare cities in equal conditions based on a given parameter, such as population size. They also highlighted the importance of weighting for a fair assessment, evaluating cities in a common basis characteristic. For instance, a context-sensitive measure might assign a higher weight to environmental sustainability in a city with a high pollution level. In contrast, measurements might prioritize public safety initiatives in a city with a high crime rate (Lai & Cole, 2023).

To identify the characteristics of context-sensitive frameworks, we conducted a literature review about SC and context-sensitive indicators. Our findings, summarized in Table 1, identify three macro dimensions and their characteristics associated with context-sensitive SCM. First, most authors emphasizes the importance of indicators related to local conditions, including economic, geographic, territorial, and social characteristics. The second dimension focuses on local needs, highlighting areas for local government actions to enhance quality of life, participation and collaboration with local stakeholders. The last dimension incorporates flexible methodologies, proposing different strategies to ensure proper comparability and customization for the cities.

Table 1. Characteristics of context-sensitive frameworks based on the literature

Dimensions	Characteristics	Sources
Local conditions	• Socioeconomic conditions • Natural and geographic conditions • Territorial conditions • Cultural and political conditions	de Oliveira et al. (2024), Gracias et al. (2023), Wang et al. (2022), Esposito et al. (2021), Alcaide Muñoz & Rodríguez Bolívar (2021), Desdemoustier et al. (2019), Sharifi (2019), Visvizi & Lytras (2018), Caird et al. (2016), Miller et al. (2013)
Local needs	• Citizen and local stakeholders' needs • Participation and collaboration • Priority areas (i.e. mobility, health, education, economy, environment, and others)	Miller et al. (2013), Malek et al. (2021), Sharifi (2019)
Methodological flexibility	• Qualitative and quantitative approaches • Indicator weights • Core and additional indicators	Lai & Cole (2023), Khatibi et al. (2022), Sharifi (2020), Sharifi (2019), Shi and Shi (2023), Lee & Lee (2014), Przeybilovicz et al. (2020)

Source: Elaborated by the authors.

Among local conditions characteristics, population size is a contextual data of cities appearing frequently to analyze SC (Desemoustier et al., 2019; Esposito et al., 2021; Wang et al., 2022). Regarding geographical characteristics, context can be related to a country (Fachinelli et al., 2023; Masik et al., 2021; Shen et al., 2018; Yadav et al., 2019), a world region (Fernandez-Anez et al., 2020; Peter et al., 2023; Marchetti et al., 2019) or smaller territories (Arief et al., 2020), such as villages, or neighborhoods (Maja et al., 2020; Visvizi & Lytras, 2018). For instance, Anand (2021), Marchetti et al. (2019), and Sharifi (2019) pointed out the lack of SCM adapted to the Global South or specific regions in the world, such as Latin America, highlighting the need for adapting or developing measurements that include their specific contexts and issues. Economic and social characteristics, such as developed or developing countries, as well as political and cultural aspects, can also be included as a contextual variable (Alcaide Muñoz & Rodríguez Bolívar, 2021). These contextual characteristics play a crucial role in shaping the governance and measurement of SC, highlighting the relevance of researching SCM according to the cities' specificities.

Another way to adhere to a context-sensitive approach is to include indicators considering local needs (Fachinelli et al., 2023; Malek et al., 2021; Miller et al., 2013; Sharifi, 2019). According to Huovila et al. (2019), a "standard indicator set should be considered as a starting point. Individual cities should thus always select and adapt indicators corresponding to their needs" (p. 150). Thus, SCM should compare cities with similar characteristics, avoiding evaluating cities together that have different needs (Sharifi, 2020). This approach can include measurements related to citizens' needs and participation as well as sectors of investments and priority areas necessary to improve people's lives, such as mobility, public safety, and housing. In this sense, Hajek et al. (2022) and Sharifi (2020) observed that most SCM did not include stakeholders participation among their indicators or in the process of measurement definition.

Some authors suggest that SCM should include a flexible methodology, for example, suggesting a combination of quantitative and qualitative approachess (Khatibi et al., 2022; Lee & Lee, 2014; Sharifi, 2020, 2019) and the inclusion of core and additional indicators (Sharifi, 2020). Methodological flexibility can also include weighting indicators to reflect their importance within an assessment scheme (Sharifi, 2020). This allows cities to differentiate indicators according to the context's importance or have an alternative to customize the SCM (Sharifi, 2020). Sharifi (2019) suggested the adoption of adjusted weights to fit different city contexts with assessment frameworks and bespoke indicators. In this sense, an example is the International Telecommunication Union's maturity model for Smart Sustainable Cities (SSC) adaptation by Przeybilovicz et al. (2020), which showed the need for customization to reflect Brazil's diverse contexts and include more context-related indicators.

While existing studies, like Caird et al. (2016), highlight the alignment of indicators with city strategy, local governments' practical use of SCM also remains underexplored. This paper specifically examines Brazilian municipalities and their implementation of SCM. Considering the need to incorporate more context-sensitive frameworks based on local conditions, needs, and methodological flexibility, this paper focuses on understanding

SCM adoption from the local government's perspective, leading to developing an understanding of context-sensitive frameworks. Therefore, considering this gap, this paper analyzes how Brazilian municipalities adopt such measurements in their SC initiatives.

3. Methodology

This paper is anchored in a qualitative approach through in-depth online interviews with representatives from Brazilian cities via a semi-structured protocol. This method allows for detailed exploration of context-sensitive SCM frameworks, providing insights from the data that can inform and enrich theoretical understanding (Gregor, 2006; Walsham, 1995). Based on the literature review, the interview script addressed five key topics: 1) respondent's background and involvement in SC initiatives; 2) city SC initiatives; 3) city measurement strategies; 4) SCM frameworks and local adaptations; and 5) external SCM frameworks influencing SC public policies.

In the last two decades, many SC initiatives have been implemented in Brazil (Cunha et al., 2016). The country is also characterized by 5,570 municipalities with different conditions, such as economic activities, geographic features, and population size (Ribeiro et al., 2020). It is also one of the most unequal countries in the world (Brazilian Institute of Geography and Statistics [IBGE], 2020), with significant regional and local disparities among socioeconomic indicators, such as access to education and healthcare, and people's income (Przeybilovicz et al., 2020). These inequalities pose challenges that can affect the development of SC in specific contexts. In this sense, Brazilian cities offer a rich source for understanding contextual factors that can make difficult or facilitate SC initiatives, including indicators about city characteristics in SCM frameworks.

Between December 2023 and February 2024, twenty-seven local government managers involved in SC initiatives were interviewed across 17 Brazilian cities, representing diverse socioeconomic and demographic conditions. This included cities from four of the five geographical regions and four state capitals. Population size was a key selection criterion, as this city characteristic is frequently presented in the literature as a fundamental contextual variable (Wang et al., 2022; Esposito et al., 2021; Desemoustier et al., 2019), categorizing analyzed cities into three groups: five with populations up to 100,000, eight between 100,000 and 500,000, and four with over 500,000 inhabitants. All cities had implemented SC initiatives and adopted SCM frameworks. Most respondents were top-level local managers responsible for SCM definition, implementation, or monitoring in their cities, including seven who were municipal secretaries mainly related to innovation, science and technology development, and urban planning or had positions in the mayor's office, and a deputy mayor. Interviews with information technology directors or those in similar positions were conducted in four cities. In other cases, the interviews included coordination positions in municipal autonomous agencies related to technology, innovation, and data offices or observatories.

The interviews were transcribed utilizing the Happy Scribe application. Data from interviews were analyzed through a deductive-inductive content analysis technique that categorized how cities adopt and use SCM in their activities according to context-sensitive dimensions found in the literature, along with additional codes that emerged during the process. One author coded the interviews, with results discussed in meetings with the other authors. Microsoft Excel was used to organize data related to the observed dimensions and to create matrices for analyzing how local governments implement SCM in their SC initiatives. Table 2 summarizes the interviews and the main characteristics of the cities.

Table 2. Characteristics of cities and respondents

Region	Interview code	Population size	Location	Number of interviewees	Interviewees positions
North	North_1	Up to 100,000 inhabitants	Non-capital city	1	Project Coordinator
	North_2	More than 100,000 up to 500,000 inhabitants	Non-capital city	1	IT Director
	North_3	More than 100,000 up to 500,000 inhabitants	Capital city	1	IT Superintendent
Northeast	Northeast_1	More than 500,000 inhabitants	Capital city	2	Director and analyst from a municipal technology and/or innovation agency
	Northeast_2	Up to 100,000 inhabitants	Non-capital city	2	Municipal Secretary in the area of public security and technical

					advisor at the Mayor's Office
South	South_1	Up to 100,000 inhabitants	Non-capital city	1	Municipal Secretary in the area of Science, Technology and/or Innovation
	South_2	Up to 100,000 inhabitants	Non-capital city	1	Director from a municipal technology and/or innovation agency
	South_3	More than 500,000 inhabitants	Capital city	1	Coordinator from a municipal technology and/or innovation agency
	South_4	More than 100,000 up to 500,000 inhabitants	Non-capital city	1	IT Director
	South_5	More than 100,000 up to 500,000 inhabitants	Non-capital city	2	Deputy Mayor and Data Office Director
	South_6	More than 100,000 up to 500,000 inhabitants	Non-capital city	2	Managers from a municipal technology and/or innovation agency
	South_7	More than 500,000 inhabitants	Non-capital city	1	Municipal Secretary in the area of Urban Planning
Southeast	Southeast_1	Up to 100,000 inhabitants	Non-capital city	1	IT Director
	Southeast_2	More than 100,000 up to 500,000 inhabitants	Non-capital city	1	Municipal Deputy Secretary in the area of Finance
	Southeast_3	More than 100,000 up to 500,000 inhabitants	Non-capital city	4	Municipal Secretary in the area of Science, Technology and/or Innovation, Municipal Secretary in the area of Management and Digital Government, Municipal Deputy Secretary in the area of Management Modernization, and Digital Services Director
	Southeast_4	More than 500,000 inhabitants	Non-capital city	1	Municipal Secretary in the area of Economic Development
	Southeast_5	More than 100,000 up to 500,000 inhabitants	Capital city	4	Undersecretary of Planning and technical analysts

Source: Elaborated by the authors.

4. Findings

This section presents the results of the content analysis of the interviews. First, we present the adoption of SCM in Brazilian cities, followed by the challenges and benefits, and finally, context-sensitive approaches adopted by the cities.

4.1 Adoption of SCM

Firstly, all representatives confirmed their knowledge of at least one SCM, collectively mentioning over 30 measurements. Local managers typically monitor results from multiple frameworks, primarily citing national SCM, with some international standards as exceptions. International standards followed by Brazilian cities included the Sustainable Development Goals (SDG) indicators, the ITU maturity model for Smart Sustainable Cities (SSC), and SC indicators from the International Organization for Standardization (ISO). Among national measurements, the Connected Smart Cities index and the Bright Cities platform were most frequently mentioned. The first ranks cities with over 50,000 inhabitants based on 70 indicators (Fachinelli et al., 2023; Fariniuk, 2020), while the Bright Cities platform assesses cities using 160 indicators across governance, education, health, urbanism, and environment dimensions (Bright Cities, n.d.). Both are supported by Brazilian consulting enterprises that providing indicators and offering services to develop SC initiatives.

The initial categorization of Brazilian cities identifies two SCM user types: observers and participants. While observers merely follow some SCM for Brazilian cities to check the results, participants play a more active role. They provide, collect, and analyze the data and results for the city and actively seek to be part of SCM proposed by external organizations. This includes sending information or registration for rankings, awards, or other ways of monitoring the SC projects and adopting recognized national and international frameworks like the SC indicators proposed by the ISO. Some of these cities have already received certification from the Brazilian Association of Technical Standards (ABNT), which ISO accredits to translate SC standards in the country, and others are in the process of certification.

Some cities frequently update data for national SCM indicators, guaranteeing that the data used is the most current and accurate one. One example was detailed by the interviewee from Southeast_3: "*One that we follow very closely is the Connected Smart Cities index. (...) we monitor how these indicators are being measured within the city government*". These indicators can also influence the actions of local governments, as pointed out by the South_6 interviewee: "*We use (…) Connected Smart Cities ranking as a means of monitoring [the city], which is divided into thematic axes. Within these axes, we can see which indicators are monitored, which criteria they use, and which data source they use. (...) based on these indicators, (...) we have meetings with the municipal departments once a year, when the indicators are released, and we plan next steps*".

Generally, they combine different external and internal indicators, showing that Brazilian local managers looked for using different sources of data according to the city context. For example, South_1 not only uses external measurement frameworks but also developed its own public relevance index, focusing on contextualized SC indicators as a small city: "*When you start looking at these manuals, you realize that you are always following the big cities. It is as if small cities are a shadow because everything is first tested in the bigger cities and, if it works there, replicated to the small cities. But, in innovation, it does not work, because you create a parameter of: You are a smart city, if you have X startups, if you have X incubators, X accelerators, and we start to question ourselves: But I will never get there. I will never have this ecosystem (...) What, in fact, considers us as a smart city*?".

Another local manager highlighted that cities should adapt the indicators to their context, not incorporating methodologies that do not include local issues: "*The ranking is not the only thing that will tell us whether we are doing well or not. Many times, it will show other cities advancing, not necessarily yours. That is why I think it is essential to have data and to have a purpose and indicators established by the policy (...) because I will look at my context. So, there are indicators and data which are often not mapped in rankings, but they are essential*" (Southeast_3). Therefore, regarding the adoption of external SCM, Brazilian municipalities not only demonstrate awareness of these models but also actively engage in monitoring and incorporating them according to their context: "*Indicators serve as a map, a guiding tool, but it is essential to consider the context of each city. This approach makes it easier to develop and implement strategies effectively*." (South_2)

4.2 SCM challenges and benefits

According to local managers, incorporating external SCM to monitor the cities' SC projects has numerous benefits. The benefits include comparisons with other Brazilian cities, enhancing the visibility and transparency of municipal actions, and attracting investment. SCM indicators also drive the engagement of public managers in SC, as it prompts government officials to respond to the reported results or take action to improve their results.

Furthermore, these frameworks enable the municipality to starting points for measurement initiatives, offer guidance on various indicators, and foster accountability by informing citizens about local government actions. In their opinion, adopting SCM also save resources and enhance city marketing and competitiveness. The following quotations highlight some advantages considered by Brazilian local managers:

"*The ranking actually publicizes how cities are doing, and this generates engagement from public managers because they want to be well-placed, showcase their city's progress, and so on.*" (South_5)

"*The key aspect (...) is having at least a minimally comparable basis to assess whether the path being followed [by the city] is indeed one that leads to improvements in public policy (...). There is also another important advantage (...) which is mobilization. Every time a ranking is released, it mobilizes the city.*" (Southeast_3)

"*We strive to keep these numbers updated and available because this is also (...) a marketing strategy for the city, enhancing its competitiveness to attract investments*." (South_7)

On the other hand, challenges mentioned by SC managers in Brazil regarding SCM adoption include a focus on larger cities, lack of standardization among different SCM, and difficulties in adapting measurement models to the unique characteristics of certain regions or contexts, such as the North and Amazon regions. The interviewer from North_1 pointed out these difficulties: "(...) *The models we have read about, (...) have looked for in the literature, do not fit our reality. The closest city here is 100 kilometers away. Everything is different when compared with the Center-West region, the Southeast region*". Because of these disparities, they opted to develop their own regional indicators to measure SC initiatives: "A*bout 40% of the indicators are global at the Brazilian level, about 70% are regionalized indicators for the North region (...) I have other difficulties (...) like access to the cities. There are cities in Amazonas State, cities in Acre State, you cannot access by roads. So, these are indicators that we must take into consideration*".

Another example is related to specific dimensions, such as transportation and mobility: "*If we look at cities that have a subway and those that do not, it is completely different. So, there's no point in suddenly adopting a methodology that incorporates the subway, and we do not have one. These things are sometimes the disadvantages of taking something closed and trying to put it that way without really adapting it to the local context*" (South_3). The requirements to have an airport close to the city were also mentioned: "*The number of airports that are taken into consideration for you to say that I am a smart city. (...) So we question the indicators for some things, that's why we look at the indicator, the source, to really know if it applies to us. If it doesn't, we need to adapt it*" (South_6).

Another challenge includes the laborious nature of data analysis. Some interviews highlighted difficulties to collect or access some indicators: "*There are indicators that require data that are not within the municipality's jurisdiction, but rather the jurisdiction of the private entity or another public organization. So, this makes it very complex. And it is not because the city does not want to show itself, it is because (...) data curation process is complex*" (Northeast_1). There are also concerns about the lack of transparency, uniformity in data availability, and the weights given to indicators among different SCM. The promotion of excessive competition among cities, particularly through rankings or indexes, was also mentioned as a challenge: "*We talk a lot about (...) not looking at rankings, because each city has its own peculiarities. (...) It is nice to be first, but there's a whole trajectory of why we are not in the first position*." (South_5). Table 3 summarizes the main benefits and challenges pointed out by Brazilian local managers.

Table 3. Benefits and challenges for adopting SCM according to the Brazilian local managers

Benefits of SCM	**Challenges of SCM**
Internal to the government • Recognition and legitimacy of the municipality's actions • Data for decision-making and management improvement • Comparison with other cities • Establishment of a baseline for indicators • Mobilization of public managers • Saving local government resources related to the creation and collection of indicators	**Lack of context-sensitive approaches** • Focus on the context of larger municipalities • Lack of in-depth analysis for specific contexts • Measurement models are not very useful for the context of some Brazilian regions, such as the North and Amazon regions • Comparison with municipalities that have different contexts • General results without segmentation according to the city's main characteristics, such as size
External to the government • Recognition and legitimacy of the municipality's actions • Attracting investments to the city • Transparency of SC initiatives • Mobilization of citizens	**SCM methodology** • Lack of transparency of SCM • Lack of standardization among indicators and weights of different SCM • Lack of in-depth indicators

• Reliability of information for society as it is provided by an external organization	**Other** • It is laborious to collect and analyze the data • Promoting excessive competitiveness to maintain position in rankings or indexes

Source: Elaborated by the authors.

4.3 Context-sensitive approaches adopted by the cities

This section presents findings from the content analysis of interviews, using the three dimensions of context-sensitive frameworks identified in the literature section. The analysis revealed new characteristics for measurement studies that could be expanded for the debates related to SCM and the local context. Among the novelties, interviews demonstrated the importance of including digital infrastructure and historical conditions in SCM frameworks, as well as the need for SCM transparency and data source flexibility.

Following the literature (Caird et al., 2016; de Oliveira et al., 2024; Esposito et al., 2021; Sharifi, 2019; Visvizi & Lytras, 2018; Wang et al., 2022), **local conditions** were emphasized by local managers, particularly the lack of context-sensitive indicators or approaches. Local managers noted the absence of indicators for small municipalities, specific regions of the country, and cultural and historical characteristics. For instance, the Connected Smart Cities Index, evaluating only cities with over 50,000 inhabitants, i.e., only 12% of Brazilian cities in 2023. Despite this limitation, the city of South_1, a small municipality, follows this index to gain insights into their SC projects and learn about other initiatives. Another example is the difficulty of finding SCM considering regional specificities, such as the municipalities in the North and Amazon regions. This region in Brazil has many natural and geographic challenges, including difficulties with Internet access. The IT manager from North_3 mentioned that there are only two fiber internet providers along the BR-364 road, and they face interruptions due to weather conditions like rain or fire. This affects critical services, making the Amazon region highly sensitive to ensuring the continuity of technology services, such as technologies highly dependent on fiber optic connection. The main adaptations to local conditions challenges pointed out by the local managers were choosing only appropriate indicators for their contexts or even creating locally relevant indicators for their specific contexts and needs, mixing external and internal measurements.

Regarding **local needs** initiatives to include citizens and local stakeholders in SC projects and measurement, some cities adopted participative approaches, particularly in developing medium or long-term goals. Some cities have official plans that received contributions from society to establish achievements for 2030 or 2040. Shorter-term goals were also mentioned, such as government plans for four-year terms. However, most cities did not involve society in the measurement process, a situation reinforced by literature highlighting the lack of SC indicators focused on citizen participation or the inclusion of the local stakeholders in SCM decisions (Malek et al., 2021; Miller et al., 2013; Sharifi, 2020). The main initiatives were related to the transparency of SC indicators: Half of the cities adopted data observatories and portals to share data related to their SC projects (Northeast_1; South_2; South_3; South_4; South_5; South_7; Southeast_2; Southeast_3; Southeast_5). According to the local manager from Southeast_2, citizens can monitor the same indicators that local managers can access internally, including ISO 37120 indicators for sustainable and resilient cities: "*We created an observatory here in the city to monitor this data and for citizens to be able to follow it with us. The same data that I monitor here as an internal manager, citizens can also follow (...). All these approximately 400 indicators are available on a web portal (...) and it is possible to monitor each one of them to keep track of the progress*". These findings echo the observations of Huovila et al. (2019) that cities are developing strategies to increase indicators transparency, including adopting dashboards. Sharifi (2019) has underscored the crucial role of SCM in enhancing governance transparency. Managers also cited priority areas for developing indicators on SC. Ten cities had initiatives to monitor the SDG in their contexts, including, in some cases, the integration and adaptation with the local government goals and policies. This link of SC-related indicators was also presented by the literature through studies that linked SCM with themes, such as sustainability and resilience (Ependi et al., 2022; Samarakkody et al., 2022; Wang et al., 2022). In some cases, the cities also prioritized SC indicators related to the most prominent social issues in the local context. For instance, a city won many prizes and awards for public safety monitoring, including technology initiatives to decrease violence against women (Northeast_2).

About **methodological flexibility**, generally, cities avoid changing SCM-defined indicators to maintain comparability and certifications, such as ISO framework or rankings: "*Adaptation is not an option. At times, we simply do not provide the data. An indicator is an indicator—it has a specific calculation and a defined data composition. (...). For the indicators we follow, either we have the necessary data, ensuring its reliability, or we do not present it*" (Northeast_1). In some cases, local managers propose different data sources according to the information available for the city, as exemplified by Southeast_4, which commissioned a survey to measure English-speaking women due to a lack of structured data. Sharifi (2019) mentioned this type of customization and considered allowing proxy data to be the main flexibility criterion proposed by SCM. Still, cities depend on the approval of the SCM organizers to include a different source for one or more indicators. Another approach is to consider missing data for indicators that are difficult to measure or not applicable to the city's context. When they do not follow officially an SCM, some cities adapt indicators to their specific characteristics, such as segmentation

by population size.

The findings suggest a lack of SCM frameworks that consider smaller cities as well as those that address the unique geographical, cultural, historical, and digital characteristics of different regions. Regarding local needs, the results emphasize the importance of measuring relevant indicators and ensuring their transparency through observatories and online dashboards. Finally, the analysis reveals that city managers hesitate to change methods to maintain comparability, though adaptations to data sources may be necessary.

5. Discussion

SCM frameworks are designed to cover many cities. This leads to the lack of context-specific indicators that capture the complexity of SC initiatives focused on cities' needs and issues (Ependi et al., 2022; Patrão et al., 2020; Sharifi, 2019; Backhouse, 2020), particularly in countries where the diversity of cities' conditions can lead to different challenges and needs. Previous studies indicated that different characteristics and levels of inequalities among Brazilian cities could affect the development of SC and the adoption of technologies by local governments (Brazilian Internet Steering Committee [CGI.br], 2022; Przeybilovicz et al., 2018; Ribeiro et al., 2020).

In this sense, the results evidenced that a single SMC framework cannot capture a Brazilian city's diversity. Among interviews with representatives from 17 cities, more than 30 SCM frameworks were mentioned, demonstrating that the city managers combine different frameworks to cover their needs to understand their SC initiatives' progress in different contexts. In contrast to the observations of Backhouse and Dhao (2020) related to the lack of SCM criticism by the cities, these municipalities did not adopt such frameworks uncritically; rather, in general, they contextualized and evaluated them from a critical perspective by combining indicators from different sources and even incorporating internal municipal indicators to monitor their SC policies.

According to local managers, the advantages of incorporating external SCM are various, verifying the advance and progress of smart city initiatives (Caird et al., 2016; Fachinelli et al., 2023; Hajek et al., 2022), attracting resources, such as investments and talent (Hajek et al., 2022), transparency for citizens about the benefits provided by SC (Huovila et al., 2019) corroborating the literature perspective on the importance of measurements covering many cities. Another crucial aspect is the possibility of comparing cities' results, an advantage mentioned by most cities. However, some challenges mentioned in balancing external comparison and context-sensitive approaches are related to focusing on the local conditions of larger cities that do not fit the context of smaller cities. Historical and cultural differences should also be considered when adapting the SCM frameworks, as well as geographic and territorial differences.

In terms of context-sensitive indicators, besides adopting external SCM, all local managers emphasized that they also have internal indicators for smart city projects, complementing external standards for monitoring their SC initiatives. For example, this includes local relevant indicators for municipal public policies in education and health sectors and according to local conditions like population size and geographic characteristics. Regarding local needs, there are more initiatives related to the transparency of SC-related indicators than those that involve the participation of society or other local stakeholders in these initiatives. Thus, there is room for improving citizens and local stakeholders' participation in both SC and SCM initiatives, as outlined by Miller et al. (2013) and Malek et al. (2021).

There is less room for adaptation in terms of methodological flexibility. From the perspective of local managers, the comparison between cities must be maintained using the same methodology. However, one recurring adaptation is the data source, which is based on the information available in the city (Sharif, 2019, 2020).

6. Conclusion

This article explores how local governments adopt and utilize SCM frameworks in their smart city initiatives. It was conducted 27 interviews with local government managers from 17 Brazilian cities and analyzed literature to identify characteristics of context-sensitive SCM frameworks. Results indicate that local conditions—such as socioeconomic, geographic, cultural, and digital infrastructure—are key for adapting SCM frameworks. Additionally, local needs including citizen and stakeholder participation, priority areas (e.g., mobility, health, education), and SCM transparency must be considered. Methodological flexibility, involving qualitative and quantitative approaches, indicator weights, and the distinction between core and supplementary data, can also enhance adaptability.

Another conclusion is that a single SCM framework is inadequate for capturing a city's complexity and measuring its SC development. Measurement models often simplify reality, making it difficult to assess the specific context. Interviews revealed that managers often use multiple models to evaluate their SC initiatives. Additionally, a dichotomy exists between addressing local context and maintaining comparability. While managers prioritize their city's specific conditions and needs, they tend to avoid flexible methodologies to prevent losing comparability.

The interview analysis shows that cities often use multiple frameworks, incorporating local indicators for internal monitoring and external ones for benchmarking. The interviews indicate that the context-sensitivity of SCM is not inherently tied to the model itself but rather to how it is appropriated, adapted, and implemented by each city. For

academia, future studies may investigate how local governments in other contexts, countries, and regions adopt and use SCM in their SC initiatives and whether this tendency to use multiple frameworks, add local indicators, and maintain comparability is also how managers appropriate and "contextualize" the models. For SC managers, the recommendation is to employ multiple frameworks, integrate local indicators, and maintain comparability.

The paper's limitations include its focus on local government officials in Brazil, potentially restricting the generalizability of findings to other countries. Additionally, the sample size may not fully represent Brazil's diversity in SC initiatives. Future studies could include comparative analysis across different countries to understand the variations in implementation, contextual factors, and other stakeholders' perspectives, such as citizens and the organizations that develop the SCM frameworks.

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