Using benchmarking to improve urban mobility: a new tool for building smart cities in emerging countries

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Abstract

Currently, smart city measurements and rankings often overlook key factors, such as size, population and economic tradition, leading to unrealistic goals being set when cities with different histories are compared with unattainable benchmarks. The present article argues that considering these factors can help city planners to achieve more efficient, incremental improvements. Focusing on mobility, this study compares a mid-sized city in southern Brazil with Aarhus, Denmark, a city of similar size and economic tradition. A diagnostic tool was developed to assess the urban mobility strengths and weaknesses of the Brazilian city through benchmarking. The results indicated that the city's urban mobility could be improved by implementing simple solutions: (i) enhancing the attractiveness of the public transport system; (ii) promoting bicycle use; and (iii) improving access to real-time information.

Keywords

Cities, urban areas, physical infrastructure, urban transport, bicycles, urban planning, urban development, quality of life, sustainable development, case studies, Brazil, Denmark

JEL classification

P25, O18, R58

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I. Introduction

The concept of smart cities has emerged in the academic literature to describe how cities integrate information technologies with public service management to automate processes and enhance citizens' well-being (Lombardi and others, 2012). Some frequently cited definitions (e.g. Neirotti and others, 2014; Jin and others, 2014; Zanella and others, 2014; and Arneodo, Castelli and Botta, 2017) emphasize technical and operational features, often at the expense of a systemic and managerial approach. This focus may lead city managers to prioritize the acquisition of technology irrespective of the actual benefits it can provide (Greenfield, 2013). According to Batty and others (2012), what makes cities smart is not merely automating routine functions but using the data generated to monitor, analyse and plan with a view to improving efficiency, equity and quality of life in real time. Hence, cities with more information and communications technology systems are not necessarily more efficient (Neirotti and others, 2014).

The difficulty of linking effort to performance in smart city projects often shifts the discussion to the political arena, where subjective issues may dominate. This is compounded by the lack of a clear, widely accepted business model for leveraging the necessary investments (Laya, Markendahl and Andersson, 2013; Zanella and others, 2014). Effective governance is essential for transforming isolated solutions into a coherent and integrated system (Gardner and Hespanhol, 2018; Praharaj and Han, 2019; Ruhlandt and others, 2020). A fundamental assumption of this project is that smart cities must make smart decisions, implementing solutions that align with citizens' needs and with available resources. Considering both priorities and resources optimizes decision-making and avoids common pitfalls associated with fashionable concepts. Creating and applying a unified information model provides a comprehensive view of urban activity (Naphade and others, 2011). Under this governance principle, a city's "smartness" is quantified by its ability to cohesively achieve its goals (JTC 1, 2015).

Holistic implementation of the smart city concept need not be immediate, as cities often have initiatives that, while isolated, are subject to some form of governance. Smart city projects can thus progress incrementally, with specific improvements, in urban mobility for example, enhancing the city's overall smartness and benefiting citizens. Benchmarking can facilitate this transformation. The main objective of this article is to propose parameters that can guide cities so that they measure themselves against realistic standards, accounting for population, size, location, economic tradition and culture before implementing projects. Urban benchmarking involves comparing the indicators of one city with those of similar units (Rok and Szmajda, 2014) and providing a clear diagnosis of development relative to a reference group. We propose a method for selecting appropriate benchmarks and establishing parameters to improve urban mobility in emerging cities. The urban mobility dimension was chosen for its direct impact on quality of life (Mylonakou and others, 2023; Chen and others, 2017), its disproportionate effect on poorer populations (Guzmán and others, 2023) and its significant contribution to urban pollution (Ghaffarpasand and others, 2024).

The study is organized into five sections after this introduction. The second section examines the theoretical background to the smart cities concept and the challenge of developing appropriate policy frameworks. The third section enlarges on the methodology employed, which is exploratory and descriptive in character. The fourth section presents the results, the fifth touches on data analysis and diagnostics, and the sixth presents conclusions.

II. Theoretical background

Cities are limited geographical areas with high population densities where goods and services flow multilaterally. Because of the concentration of people and services, they tend to attract incomers (Polèse, 2010). This concentration creates specific demands and consumes part of the city's wealth

(Newman, 1999). However, addressing these self-generated problems can drive innovation, stimulate economic activity and generate more wealth (Schaffers and others, 2011; Mora, Deakin and Reid, 2019). Conversely, unresolved issues lead to inefficiency, environmental problems and reduced citizen satisfaction (Hollands, 2015; Kumar, 2017; Ghaffarpasand and others, 2024).

Scholars advocate a systemic approach to managing and understanding smart cities (Fu and Peng, 2014; Hollands, 2015). Viewing a city as a metasystem highlights the complexity that city managers face and the interconnectedness needed for resource optimization (Naphade and others, 2011). Caragliu, Del Bo and Nijkamp (2011) describe a smart city as one where investments in human and social capital, along with traditional and modern communications infrastructure, fuel sustainable economic growth and high quality of life through participatory governance. The defining feature of a smart city is not its infrastructure but how citizens interact with these systems and each other (Walravens and Balon, 2013). Smartness involves integrating various urban fields into a unified governance system to optimize resource allocation for citizens' well-being (Angelidou, 2017).

Smart cities, as sophisticated systems, incur high costs owing to redundancy. Efficiency can be gained by identifying and reducing duplicated capabilities (Maier, 1998). This means identifying all city systems and establishing a governance arrangement to intertwine them. The challenge of building a smart city involves identifying and integrating existing systems (Zhuhadar and others, 2017). This integration provides city managers with quality data for informed decision-making (Neirotti and others, 2014). A core goal in planning a smart city is aggregating real-time information to address challenges and manage resources effectively (Fu and Peng, 2014; Ardito and others, 2019). Three main approaches define smart cities, one of them technological, one humanistic and one managerial. The technological approach focuses on using smart computing technologies to interconnect city activities (Washburn and Sindhu, 2010). This interconnectivity integrates complex data into a platform that informs operational decisions (Harrison and others, 2010). The humanistic approach views smart cities as those that meet community needs, with creativity being a key aspect (Albino, Berardi and Dangelico, 2015). The managerial approach defines smart cities as those that excel in terms of their economy, people, governance, mobility, environment and quality of life by leveraging the endowments and activities of informed citizens (Nam and Pardo, 2011).

Berrone and Ricart (2018) presented the cities in motion index, which analyses nine city dimensions to identify strengths and weaknesses with a view to contributing to development planning and a better quality of life. The ISO 37122:2019 standards provide indicators for analysing smart cities across various areas, emphasizing coordinated city functions and stakeholder interactions within a smart macro system (Fu and Peng, 2014; Kumar, 2017). Managing smart cities is complex because of the diversity of data sources, and requires active, problem-solving governance that values collaboration (Goldsmith and Crawford, 2014; Barns, 2018). Collaborative, data-driven models of governance open government processes to citizens, fostering co-produced solutions. Data can streamline government services, replacing bureaucratic structures (Clarke and Margetts, 2014; Davies and Bawa, 2012).

The challenge is to develop policy frameworks that facilitate investment in data-driven services aligned with city priorities. Each smart city is unique, requiring tailored models (Kumar, 2015). Balancing social development and economic growth in a highly urbanized context drives interest in smart cities, necessitating strategies that integrate multiple sectors into a systemic vision. However, some scholars view the city as a collective entity, behaving like a homogeneous body with one voice (Vanolo, 2014). Urban mobility, a critical dimension of smart cities, directly impacts quality of life (Mylonakou and others, 2023; Chen and others, 2017). Efficient urban mobility solutions can reduce traffic congestion, lower greenhouse gas emissions and improve accessibility (Guzmán and others, 2023; Ghaffarpasand and others, 2024). Recent advances with autonomous vehicles, shared mobility services and real-time traffic management systems highlight the potential for smart technologies to revolutionize urban transport (Cohen and Shaheen, 2016; Acheampong and others, 2020).

III. Method

The methodology employed in this paper is a case study. Data collection and analysis adopted a heterodox approach, incorporating both qualitative and quantitative data from primary and secondary sources. This approach was deemed appropriate given the nature of the research problem, the absence of a unified source encompassing all pertinent information and the necessity of incorporating diverse perspectives to achieve data triangulation and an unbiased diagnosis (Yin, 2018; Baxter and Jack, 2008; Flyvbjerg, 2011; Matyas and Kamargianni, 2021).

This study is exploratory and descriptive, aiming to provide a better understanding of the mobility phenomenon, describe the characteristics of the subject in specific cities and establish connections between variables. The case study approach is particularly suitable for exploratory and descriptive research, as it is the most comprehensive type of research design. It encompasses both "people data" and "paper data", utilizing a wide range of information sources that include personal interviews and website analysis (Gil, 2002; Stake, 1995; Crowe and others, 2011). By employing a case study methodology, this research benefits from a flexible, in-depth examination of the subject matter, allowing for a nuanced understanding of complex issues within real-world contexts (Flyvbjerg, 2011).

1. The research context

Brazil's Growth Acceleration Programme (PAC 2) for Urban Mobility has allocated approximately 40 million reais since June 2018 for the implementation of bus lanes, asphalt repair on bus routes and the development of commuter stations in the city of Caxias do Sul (Ministry of Planning, Development and Management of Brazil, 2016). This programme aims to reduce social inequalities by prioritizing public transport, thereby transforming cities into more humane environments. To achieve this goal, the State of Rio Grande do Sul supports "projects that promote the physical and fare integration of public transport, as well as large- and medium-capacity projects, such as underground railways, bus rapid transit, bus corridors, light rail vehicles and aerial vehicles, among others" (Ministry of Urban Affairs of Brazil, 2015).

Given that Caxias do Sul is actively pursuing smart city initiatives and making the corresponding investments, a comprehensive evaluation of the city's needs in various sectors is necessary. This study specifically explores urban mobility as a critical area for improvement, recognizing it as a fundamental step towards achieving the city's ambitious goals.

2. Data collection

To identify suitable projects for the city of Caxias do Sul with a view to enhancing its mobility infrastructure, the data collection process for this study was divided into two distinct segments: (i) collection of mobility data specific to Caxias do Sul; and (ii) collection of mobility data from a city that is a benchmark in the field. For the first segment, a diagnostic tool was utilized to assess the present state of urban mobility in Caxias do Sul according to internationally recognized standards. This tool is elaborated upon in subsection 3 below. Following the application of the tool, the findings were compared with those for the benchmark city, which was selected on the basis of the criteria outlined in point (b) below. Table 1 lists the primary information sources employed to gather the requisite data for this study.

Table 1
Data sources used in the study

Source	Information type	Collection method
Ministry of Planning and Budget [online] https://www.gov.br/planejamento/pt-br	Investments in the city	Online
Caxias do Sul Cycling Union (UNICCA)	Cycling infrastructure projects	Telephone
MobiCaxias[a]	Urban mobility projects	Telephone
Viação Santa Tereza (VISATE) (public transport company)	Bus quality, coverage, usage and satisfaction level	Email
Caxias do Sul City Hall [online] https://caxias.rs.gov.br/	City demographic information	Online
Rádio Caxias (radio station) [online] https://radiocaxias.com.br/portal/noticias/prefeitura-estuda-criacao-de-ciclofaixa-que-ligue-as-zonas-leste-e-oeste-de-caxias-do-sul-111274	Cyclists' views on cycling conditions in the city	Online
Pioneiro (local newspaper) [online] http://pioneiro.clicrbs.com.br/rs/politica/noticia/2019/06/gestao-de-mobilidade-urbana-em-caxias-vai-na-contramao-do-que-e-adequado-dizem-especialistas-10942793.html	Increase in car ownership over the years	Online
Viação Santa Tereza (VISATE) (public transport company) [online] https://www.visate.com.br/site/	Frequency of bus services	Online
Aarhus Kommune	Public transport quality, coverage, usage and satisfaction, and number of private cars	Email
Cycling Embassy of Denmark and Aarhus Landscape Architecture Platform	Cycling infrastructure, number of cyclists, increase in cycle use	Email
Municipality of Aarhus [online] https://aarhus.dk/	Investments in the Aarhus smart mobility project	Online
VisitAarhus [online] https://www.visitaarhus.com/corporate/about-organisation-visitaarhus	Means of transport	Online
State of Green, *Sustainable Urban Transportation*, 2016 [online] [online] https://cyclingsolutions.info/wp-content/uploads//2020/12/Sustainable-Urban-Transportation.pdf	Aarhus's plans for sustainable mobility	Online
International Centre, "Buses in Aarhus", Aarhus University, 2016 [online] https://www.au.dk/fileadmin/www.au.dk/Internationalt_Center/Housing/Practical_social/BUSES_in_Aarhus.pdf	Bus fares	Online
M. S. Nicolaisen, "Mobility and Urban Development in Aarhus", n.d. [online] https://bransch.trafikverket.se/contentassets/b9cca53e177349d39d98584b597f3674/mobility-and-urban-development-in-aarhus-morten-skou-nicolaisen.pdf	Aarhus demographics and description of the city	Online
International academic resources	Means of transport	Online
LetsGo - Lev simpelt (car sharing service) [online] https://letsgo.dk/om-letsgo	Car sharing	Online
Smart Aarhus [online] https://aarhus.dk/	Mobility as a service programme	Online
Donkey Republic (bicycle sharing service) [online] https://www.donkey.bike/	Bicycle sharing programme	Online
Minimum-Wage.org [online] https://www.minimum-wage.org/	Minimum wage	Online
IQAir [online] https://www.iqair.com/	Air quality	Online

Source: Prepared by the authors.

[a] The civil society organization Mobilization for Caxias do Sul (MobiCaxias) is founded on principles and conceptual frameworks aligned with the academic literature on innovation and innovative ecosystems in Brazil. It is structured around the triple and, more recently, quadruple helix models, which include the active participation of representatives and leaders from four key sectors: public sector (executive and legislative authorities), private sector (business entities), academia (universities and colleges) and organized civil society. The latter includes unions, associations and other community, cultural and social institutions and organizations, as well as individuals who are united in their commitment to envisioning and building a prosperous future for Caxias do Sul.

(a) Tool for diagnosing mobility in Caxias do Sul

An analysis of mobility in Caxias do Sul was conducted for the initial phase of data collection in this study. To evaluate the efficacy and functionality of the city's mobility options, the indicators listed in table 2 were employed, drawing upon the research conducted by Tischer and Polette (2019) on urban mobility assessment. This methodology was selected for its capacity to bring out factors that significantly impact city residents' quality of life and transportation, including cycling infrastructure,

urban design, public spaces, public transport, length of commutes and private vehicle usage. Tischer and Polette (2019) emphasize that these indicators are widely recognized and employed globally, with their findings serving not only to evaluate a city's performance but also to propose enhancements to its urban processes.

Table 2
Mobility quality indicators

Indicator	Aspects measured
Urban mobility innovation index (International Association of Public Transport)	Population size and density; public transport use; public transport frequency; financial attractiveness of public transport; level of public satisfaction with the public transport system; area of the city that has access to the public transport system; public sector encouragement of public transport; registered vehicles; inhabitants per car; car sharing
Copenhagenize index	Public support for and culture of bicycle use; special facilities for bicycles; cycle lane or path infrastructure; bicycle sharing programmes; bicycle use by gender; bicycle use as a means of transport; increase in bicycle use; perceptions of safety; public policies and urban planning; social acceptance; cargo and logistics bicycles
European Green Capital Award	Nature and biodiversity; sustainable mobility; air quality and waste
Quality of living ranking (Mercer)	Natural spaces; transport options provided by the city
Walk score	Distance between homes and the public transport system

Source: Prepared by the authors, on the basis of V. Tischer and M. Polette, "Sistema de avaliação de cidades de referência em transportes e mobilidade urbana sustentável", *Cadernos Metrópole*, vol. 21, No. 45, May–August 2019.

(b) Mobility in the benchmark city

In the subsequent phase of this study, data from Aarhus in Denmark were examined. Aarhus was selected as the benchmark against which Caxias do Sul was to be compared owing to its recognition as the second-ranked smart city globally and the third-ranked for mobility (Vienna University of Technology, 2014) and because of its considerable comparability with Caxias do Sul across various dimensions. Aarhus is the second most populous city in Denmark, with approximately 350,000 residents, while Caxias do Sul is the second-largest city in the state of Rio Grande do Sul, a region akin to Denmark in both size and population. Aarhus has experienced considerable population growth and is home to a prominent university attended by over 40,000 students. Moreover, the city's harbour is predominantly industrial, with its container port ranking as Denmark's largest, and primarily carries out export of grains (UrbanAct, 2020).

Caxias do Sul similarly hosts a significant university and relies mainly on industrial sectors for its economic sustenance. Given Aarhus's standing as the third-ranked smart city for urban mobility and its substantial comparability with Caxias do Sul in terms of size and economic profile, it was deemed an appropriate benchmark. The data collection process for Aarhus was divided into two components: (i) compilation of data obtained using the diagnostic tool developed to assess mobility in Caxias do Sul (the indicators listed in table 2); and (ii) a comprehensive description of the primary mobility initiatives undertaken by the city. These amalgamated data were then analysed to identify measures applicable to Caxias do Sul and elucidate potential adaptations or analogous concepts.

(c) Data analysis

The scope of the factors required for a city to transition into a smart city is extensive, making it impractical to comprehensively analyse all facets within the confines of this study. However, as posited by Naphade and others (2011), a prudent approach is to identify a single area for improvement as a starting point for progress. Consequently, this study focuses on the mobility aspect of smart cities. To achieve the objectives of this study, the data triangulation method was employed for data analysis. This

method was selected because of its ability to synthesize data from multiple sources, in the recognition that reliance on a single data source would be likely to yield insufficient information. Thus, the utilization of both qualitative and quantitative sources in tandem was deemed imperative, as they provide complementary insights that can enrich the overall analysis process (Creswell and Clark, 2011). The incorporation of mixed data into the triangulation framework serves to mitigate potential bias in single-faceted research methodologies, particularly qualitative approaches, thereby facilitating the attainment of more accurate and veracious outcomes (Holland, 2009).

IV. Results

The results were spliced into three main sections: (i) the quality of urban mobility in Caxias do Sul, as ascertained from the results for the table 2 indicators; (ii) the quality of urban mobility in Aarhus, as ascertained from the results for the table 2 indicators; and (iii) Aarhus's mobility plans.

1. Quality of urban mobility in Caxias do Sul

To obtain the results that follow, we interviewed the executive director of MobiCaxias and the leaders of the Caxias do Sul Cycling Union and of Viação Santa Tereza (VISATE), the company that runs the city's public transport system. We also consulted the websites of the city's prefecture, the local radio station and *Pioneiro* newspaper, the Murbi transport service, *Diário do Transporte* online news service, PwC and the Caxias do Sul Taxi Association (ACTL), as well as a study on mobility and tourism by Simon, Gastal and Dos Santos (2014) and research into the sustainability of urban waste disposal (Caxias do Sul, 2024).

(a) Urban mobility index

Analysis of Caxias do Sul's urban mobility index provides several key insights into the city's public transport system. Managed by a private company, the system caters to approximately 90,000 passengers monthly, with a reported satisfaction rate of 75.9%. Each bus operates an average of 5.8 trips per day across 82 routes, ensuring comprehensive coverage of the city's urban areas. Despite the system's extensive reach, however, its financial attractiveness is deemed relatively low, as evidenced by the one-way ticket price of 4.80 reais. Considering that the city's minimum wage stands at approximately 5.80 reais per hour, acquiring a return ticket to commute between home and work necessitates more than one hour of work.

With a population of approximately 500,000 and a population density of 280.52 inhabitants per square kilometre (IBGE, 2022), Caxias do Sul also has to cope with high vehicle density, since there are approximately 306,000 registered vehicles in the city, equating to 1.6 inhabitants per vehicle. In response to these challenges, the city has outlined plans to introduce special parking spaces for shared cars by 2024 as a means of promoting car-pooling initiatives.

Furthermore, alongside the conventional bus system, Caxias do Sul offers two additional modes of public transportation: the Murbi system and shuttle services. Murbi operates on an on-demand basis, primarily catering to students and faculty members of the University of Caxias do Sul. Users can access the service via a dedicated mobile application, selecting from predetermined routes and opting for either Murbi Pop, priced at 2.00 reais per ride, or Murbi Easy, priced at 5.20 reais per ride and offering door-to-door drop-off services.

The shuttle service operates much like a standard bus service, but on a more limited scale, serving only four routes within Caxias do Sul. Positioned as a premium transport option between buses and taxis or ride-sharing services, the shuttle accommodates a maximum of 20 passengers per trip, with a fare of 3.60 reais per ride. The shuttle service currently faces operational challenges, with approximately 20 vehicles operating under suboptimal conditions.

To optimize urban mobility and address transport disparities, Caxias do Sul needs to prioritize strategic interventions aimed at enhancing the accessibility, affordability and efficiency of public transport. Implementing targeted initiatives, such as shared parking facilities and improved shuttle service operations, could facilitate the city's transition towards a more sustainable and equitable urban mobility ecosystem.

(b) Copenhagenize index

The analysis of the urban mobility index revealed a conspicuous lack of robust public support for cycling as a viable mode of transport within Caxias do Sul. Cycling is understood in the city predominantly as a recreational or sporting activity and is overshadowed by a pervasive "car culture" that treats cycling as a subordinate choice for commuting. Despite sporadic promotional events aimed at fostering cycling engagement and centring primarily on recreational pursuits, cycling as a mode of transport remains marginal.

The city's cycling infrastructure exhibits significant deficiencies, in particular a dearth of designated cycle paths and lanes, with only two currently in existence. Furthermore, this infrastructure is poorly planned, as it is not designed to take in points of interest or provide optimal connectivity across the city. Critical amenities, such as bicycle parking facilities, are only sporadically available, primarily at a selection of establishments such as shopping centres, universities and restaurants, which further constrains accessibility and convenience for cyclists.

While grass-roots calls for improved cycling infrastructure have spurred some municipal initiatives since July 2018, including proposed cycle tracks spanning the city and a 1.7 km cycle lane in the Ana Rech district, progress remains sluggish. Held back by inadequate infrastructure and safety concerns, the adoption of cycling as a viable mode of transport progresses at a lethargic pace. Vital prerequisites for a cycling-friendly environment include comprehensive cycle track systems and secure parking facilities to safeguard cyclists' well-being and promote a modal shift. Moreover, engendering a cultural shift in societal perceptions of cycling, beyond its recreational connotations, is paramount to foster broader social acceptance and uptake.

In the realm of cargo transportation, the emergence of delivery apps has spotlighted the potential utility of bicycles for logistical purposes. However, the absence of a formal cargo cycling infrastructure, coupled with the lack of a regulatory framework, precludes the widespread adoption of cargo cycling initiatives within the city. Despite burgeoning interest, the prospects for integrating cargo bicycles into Caxias do Sul's transport ecosystem remain nebulous in the absence of concerted municipal efforts to formalize such initiatives.

(c) European Green Capital Award

Caxias do Sul's urban landscape is poised for transformation, with plans under way to develop and furnish urbanized public spaces across the city. By 2024, it is anticipated that 50% of Caxias do Sul's public areas will have been comprehensively inventoried and neighbourhood-specific utilization plans and maintenance strategies will be in place. The initial plan was to convert Júlio de Castilhos Avenue into a linear park by 2022, incorporating commercial and service amenities to enhance public accessibility

and recreational opportunities. Owing to public opinion and operational challenges, this transformation did not take place. Nevertheless, the project has been included in the new mobility plan and remains part of the city's goals, with completion now projected for 2030.

In line with Sustainable Development Goal (SDG) target 11.2, Caxias do Sul is endeavouring to develop a more sustainable, inclusive and equitable urban mobility framework by 2030. Concurrently, efforts to achieve SDG target 11.6 involve implementing comprehensive air quality and waste management protocols, with the aim of mitigating adverse environmental impacts. Caxias do Sul ranks as the fifth most sustainable city in Brazil for urban sanitation, attesting to its compliance with legal prescriptions governing solid waste management from collection to disposal.

Caxias do Sul currently boasts commendable air quality, with a United States air quality index (AQI) score of 47 based on data for the week from 9 November to 15 November 2020. However, while this score is within the "good" range, a relatively small rise to 51 on the AQI would take it into the inferior category of "moderate" air quality. Ongoing monitoring and proactive measures are therefore essential to sustainably manage air quality levels and preserve environmental integrity within the urban milieu.

(d) Mercer quality of living ranking

Analysis of this ranking reveals that Caxias do Sul is making strides towards SDG target 11.7, which is to provide universal access to safe, inclusive and accessible, green and public spaces by 2030, with a particular focus on vulnerable groups, such as women, children, older persons and individuals with disabilities. This underscores the city's commitment to fostering equitable and accessible urban environments conducive to social inclusion and well-being.

Abrantes (2016) conducted a comprehensive assessment of Brazilian cities, encompassing well-being, safety, education, health and economic indicators, among other dimensions. Caxias do Sul earned the distinction of being ranked eighteenth on these criteria, reflecting its good overall performance across multiple domains. This recognition underscores the city's ongoing efforts to enhance liveability, promote socioeconomic development and foster an enabling environment for its residents.

(e) Walk score

Regrettably, data on the walkability score for Caxias do Sul were not accessible. This underscores the data deficits that prevail in many developing nations, in particular for their urban centres. These lacunae are probably attributable to fundamental societal needs, such as healthcare and education being prioritized in resource allocation, which limits the availability of comprehensive data on urban infrastructure and liveability indices.

2. Quality of urban mobility in Aarhus

To acquire the information presented below, correspondence was initiated via email with key stakeholders, including the Head of Transport Planning of Aarhus, the Cycling Embassy of Denmark and a landscape architecture platform affiliated with Aarhus. In addition, information was extracted from various websites, such as those of the municipality of Aarhus, the Danish Ministry of Environment, Visit Aarhus, international academic resources, LetsGo - Lev Simpelt, Smart Aarhus, Donkey Republic and Minimum-Wage.org. Relevant research materials were also consulted, including "Buses in Aarhus" (International Centre, 2016), and *Sustainable Urban Transportation* (State of Green, 2016).

(a) Urban mobility index

Analysis of this index shows that public transport in Aarhus has a considerable ridership of between 40 million and 45 million passengers a year. The light rail and primary bus lines operate at frequencies ranging from 6 to 12 departures per hour during peak periods, and an impressive 70% of public transit users rate the service at between 7 and 10 on a scale of 0 to 10. Moreover, the entire city is effectively served by public transit, overseen by five regional public bus companies. Various ticketing options are available, the most prevalent being the 30-day pass, priced at 365 kroner as of 2020 (approximately 308 reais), which permits unlimited rides within the designated period. As regards affordability, with the minimum wage set at 18 kroner (roughly 15.20 reais) per hour, the cost of a round-trip ticket equates to less than an hour's labour.

Aarhus, home to nearly 350,000 inhabitants, has a population density of 2,874 people per square kilometre and 119,825 registered private vehicles, translating to nearly three inhabitants per car. Notably, the city hosts several car-sharing initiatives, with LetsGo - Lev Simpelt being a prominent example. Membership of this organization gives people access to a fleet of shared vehicles that are available for booking as needed. Members typically pay a monthly subscription fee plus fuel and mileage costs accrued during usage. The precise rental fee for each booking may vary depending on the subscription plan selected.

(b) Copenhagenize index

It is evident from this index that Aarhus fosters a robust cycling culture, with bicycles serving as a major mode of transportation. The city embarked on the implementation of its Cycling Action Plan in 2007, and this resulted in the establishment of various initiatives, including the creation of new cycle routes and paths, the installation of over 3,000 bicycle parking facilities, the deployment of additional traffic signage, air pumps and bicycle barometers, and enhanced snow clearance efforts during the winter. Aarhus boasts an extensive cycling infrastructure comprising 675 km of cycle lanes. Furthermore, the city has a bike-sharing programme operated by Donkey Republic, which allows users to rent bicycles via a mobile application for flexible durations.

Cycling demographics in Aarhus are notably diverse, with an even split between male and female cyclists. Over 50% of cyclists are employed, while 26% are students and 22% fall into the non-employed or other categories. Remarkably, 85% of the population has access to a bicycle, with 58% cycling regularly. There is a growing trend towards the adoption of cargo bicycles, which constitute 3% of the total cycle fleet and are primarily utilized for transporting children and goods.

Reflecting the broader cycling ethos of Denmark, Aarhus has witnessed a considerable surge in bicycle usage over the past decade, with a 20% increase recorded. Future plans, as outlined in 2019, encompass the construction of two new cycling superhighways, the development of a bicycle parking facility at the main train station capable of accommodating 2,000 bicycles, and the introduction of three fully automated bicycle parking towers inspired by similar structures in Japan.

(c) European Green Capital Award

Aarhus has undertaken significant initiatives in the realm of sustainable mobility since 2016, forging partnerships with more than 40 climate partners to address traffic congestion and promote sustainable mobility practices. Emphasizing public-private collaboration, these efforts aim to incentivize investment in both areas with a view to creating a more environmentally friendly transportation landscape. Within

Aarhus's business district, notable developments include the inauguration of a light rail system in 2017, complemented by plans to establish a comprehensive network of cycling paths integrated with bus stops and light rail stations. In addition, the business park intends to provide employees with access to a range of bicycles and cargo bicycle services for small-scale deliveries, further encouraging eco-friendly commuting practices. A key objective of the city is to achieve carbon neutrality in the foreseeable future.

As regards air quality, Aarhus currently has favourable conditions, with an AQI score of 28 during the week of 9 November to 15 November 2020.The city makes it a priority to maintain minimal AQI levels, indicative of high air quality. Notably, Aarhus has garnered acclaim for its innovative waste management strategies since 2012. The implementation of over 800 underground waste containers has significantly enhanced waste collection efficiency, reduced noise pollution associated with traditional waste disposal methods and mitigated odour-related concerns. Moreover, this initiative has garnered widespread public approval, with over 90% of residents expressing satisfaction with the improved waste management infrastructure.

(d) Mercer quality of living ranking

Aarhus offers a plethora of green and accessible spaces, boasting over 20 parks that cater to diverse recreational activities, such as sports, leisurely strolls and family outings. These parks serve as vibrant communal hubs where residents can immerse themselves in nature, engage in physical activities or simply unwind amidst verdant surroundings and serene bodies of water. Regarding transportation options, Aarhus provides a comprehensive range of choices, including buses, the light rail system (Aarhus Letbane), bicycles, personal vehicles and taxis. Nomad List, a prominent website specializing in city rankings, conducted an assessment of the most desirable Danish cities for residents, considering a variety of factors, such as walkability, weather conditions, cost of living, educational opportunities and safety standards. In this assessment, Aarhus ranked third, confirming its appeal as an attractive urban destination characterized by favourable living conditions and amenities.

(e) Walk score

Around 99% of public transport users live within 800 m of their nearest bus stop.

3. Aarhus's plans for mobility

In 2007, the Municipality of Aarhus implemented a Cycling Action Plan aimed at enhancing the quality of cycling infrastructure to promote cycling as a primary mode of transportation. The plan's objective was to increase the number of individuals opting for bicycles, thereby yielding positive outcomes for Aarhus's public health, climate and traffic congestion mitigation efforts. This strategy was underpinned by the recognition that cycling offers health benefits, produces zero CO2 emissions and substantially reduces congestion and traffic jams (Aarhus Kommune, 2024).

In 2017, furthermore, Aarhus introduced the concept of mobility as a service, which prioritizes solutions, such as car-pooling and traffic reduction. Concurrently, the city launched the GoTur mobile application, designed to integrate various transportation modalities including buses, trains, light rail, bicycle-sharing schemes and electric scooters. Available for download on both the Android and the iOS platforms, GoTur asks users to input their current location and desired destination and then furnishes them with optimized route suggestions encompassing public transit, cycling options, electric scooters and ride-sharing services provided by private motorists.

4. Overall results

The indicator data gathered for both Caxias do Sul and Aarhus are presented in table 3. It should be noted that Aarhus has launched an open data initiative aimed at giving citizens access to a range of information sets covering various domains, including urban mobility. Caxias do Sul has recently initiated a similar open data project, though it remains in the developmental phase. The use of open data is of paramount importance in the effort to achieve smart city status. This initiative helps researchers and businesses to refine their offerings by leveraging insights from different data sets. It also affords developers the opportunity to devise applications predicated on real-time data, spanning domains such as transport and health care. Thus, both municipalities are positioned to embark on a trajectory of enhanced data availability in which disparate data sources are effectively integrated to facilitate enhanced urban management practices.

Table 3
Indicators and results

Indicator	Aspect measured	Results for Caxias do Sul	Results for Aarhus
Urban mobility innovation index	Population size	About 500,000 inhabitants	About 350,000 inhabitants
	Population density	280.52 inhabitants per km^2	2,900.00 inhabitants per km^2
	Public transport use	1.08 million passengers a year	40 million passengers a year
	Public transport frequency	2.5 times per hour	6 times per hour
	Financial attractiveness of public transport	Low	High
	Level of public satisfaction with the public transport system	75.9%	70%
	Area of the city that has access to the public transport system	100%	100%
	Public sector encouragement of public transport	The system is run by two private companies	The system is run by five regional public bus companies
	Registered vehicles	306,029	119,825
	Inhabitants per car	1.6	2.8
	Car sharing	The plan to implement special parking spaces for car sharing by 2024 was not implemented	Aarhus has a number of car-sharing associations, such as LetsGo - Lev Simpelt
Copenhagenize index	Public support for and culture of bicycle use	The city has a "car culture" with almost no public support for bicycle use	Aarhus has a culture of bicycle use, and more than 150 million kroner has been invested in promoting cycling over the past few years
	Special facilities for bicycles	Only a few establishments such as shopping centres, universities and a few restaurants offer bicycle parking	The city's Cycling Action Plan (2007) included: (i) creating new cycle routes; (ii) creating new cycle paths; (iii) creating parking for more than 3,000 bicycles; (iv) installing new traffic signs, air pumps and bicycle barometers; and (v) enhancing snow clearing in winter
	Cycle lane or path infrastructure	Only two isolated cycle lanes	675 km of cycle lanes
	Bicycle sharing programmes	None	Donkey Republic bicycle sharing programme
	Bicycle use by gender	No information on bicycle use as a means of transport, but sporting use is mainly by men	50% of users are men and 50% women
	Bicycle use as a means of transport	Still mainly seen as a leisure activity	85% of the population has access to a bicycle and 58% cycle on a regular basis
	Increase in bicycle use	Slow increase	20% increase in the past 10 years
	Perception of safety	Bicycle use is perceived as unsafe, which keeps numbers from growing	Unavailable
	Public policies and urban planning	Lacking, although Caxias do Sul Cycling Union (UNICCA) advocates for them	Plans for the future include the construction of two new cycle superhighways, a bicycle parking facility at the main train station with a capacity of 2,000 parking places and three fully automated bicycle parking towers
	Social acceptance	Low, with little visibility and few incentives	Like all of Denmark, Aarhus has a very strong cycling culture, and cycling is a highly acceptable means of transport
	Cargo and logistics bicycles	Only used for deliveries ordered through applications	3% of bicycles are cargo bicycles, mainly used to transport children and goods

Indicator	Aspect measured	Results for Caxias do Sul	Results for Aarhus
European Green Capital Award	Nature and biodiversity	The plan for urbanized public spaces to be developed and available throughout the city by 2024 and for Júlio de Castilhos Avenue to be a linear park with commerce and services by 2022 was not implemented	Unavailable
	Sustainable mobility	In line with SDG target 11.2, the aim is to have a more sustainable, inclusive, effective and fair urban mobility system by 2030	Aarhus has partnered with over 40 climate partners since 2016, seeking ways to reduce congestion, make mobility more sustainable and encourage the public and private companies to invest in these ideas, while also aiming to be carbon-neutral in the near future
	Air quality and waste	The plan is for all cities with more than 500,000 inhabitants to have implemented methods of tracking air quality and waste by 2030, so as to reduce negative impacts; Caxias do Sul currently scores an AQI of 47, which is good but almost bordering on moderate	Aarhus currently has an AQI score of 28 (good air quality) and is recognized for the waste management and collection strategies it has had in place since 2012
Quality of living ranking (Mercer)	Natural spaces	The plan is for Caxias do Sul to provide universal access to safe, inclusive and accessible, green and public spaces by 2030, in particular for people with disabilities and other vulnerable groups	Aarhus has many green and accessible places, with more than 20 parks where people can take their children, practise sports and relax amid green surroundings and water
Quality of living ranking (Mercer)	Transport options provided by the city	Buses (run by one private company), shuttle services, the Murbi on-demand system, personal vehicles, taxis and the Uber application	Buses (run by five regional public companies), the Letbane light rail system, cycling (numerous cycle tracks and a bicycle sharing system), personal vehicles and taxis
Walk score	Distance between homes and the public transport system	Unavailable	99% of public transport users have a bus stop within 800 m of their home

Source: Prepared by the authors.

V. Data analysis and diagnostics

Analysis of the data presented in this paper revealed numerous areas and avenues for improvement in Caxias do Sul. The primary recommendations include: (i) increasing bicycle use and reshaping public perceptions of cycling; (ii) enhancing the attractiveness of public transport; and (iii) developing a comprehensive application that integrates traffic information and transport options. Another recommendation is for the municipality to enhance its data management system and show greater commitment to project implementation (Flyvbjerg, 2011; Zhang, Gao and Mei, 2018; Matyas and Kamargianni, 2021).

Caxias do Sul stands to benefit from an improved approach to bicycle infrastructure and cyclist relations, drawing insights from the substantial positive developments observed in Aarhus's urban mobility. A concerted effort to enhance cycling infrastructure, including dedicated lanes and special parking facilities, is warranted. Initiatives to improve cyclists' perception of safety, coupled with educational efforts in schools and transit departments, are also advocated to promote cycling as a viable mode of transport. The importance of accessibility is underscored by the efficacy of Aarhus's bicycle-sharing system, and the introduction of an affordable programme of this type, potentially incorporating electric bicycles tailored to the city's topography, is suggested.

Caxias do Sul's aspirations to develop green natural spaces also require greater efforts, in line with the ISO smart city recommendations. While Aarhus has a plethora of verdant, accessible parks, Caxias do Sul's plans for such spaces remain nascent. Furthermore, the imperative of ensuring good air quality, a hallmark of smart cities, reinforces the need for sustainable mobility initiatives. Efforts to achieve carbon neutrality, reduce traffic congestion and incentivize public transport and cycle use are advocated.

The disparity between transport preferences in Caxias do Sul and Aarhus underscores the need to enhance the appeal of public transport in the former. Strategies to make bus fares more affordable and develop real-time mobility applications, in line with Aarhus's example, have been proposed.

It is also vital to address deficiencies in data management and project implementation. Enhanced data collection, storage and accessibility are advocated, alongside a more steadfast commitment to project execution.

While progress in enhancing urban mobility in Caxias do Sul represents a major stride towards smart city status, it is acknowledged that broader challenges persist. A nuanced approach, anchored in feasible benchmarks and incremental advances, is recommended. Furthermore, it is imperative to deal with the disparity in data availability and implementation efficacy between Caxias do Sul and Aarhus, which is indicative of broader governance and infrastructure challenges. The Urban Transport and Mobility Master Plan (Planmob) is a pivotal initiative, but effective implementation will require political will, financial resources and community engagement.

In conclusion, while the recommendations outlined here, if implemented, would represent major steps towards enhanced urban mobility, they represent only a fraction of the multifaceted endeavour required to turn Caxias do Sul into a smart city. Nonetheless, a concerted effort underpinned by actionable strategies and robust governance frameworks would hold out the promise of an improved urban mobility landscape and incremental progress towards smart city status.

VI. Conclusions

The review of existing research and studies that was conducted for this paper has made it clear that many multifaceted elements go to make a smart city. This holistic concept encompasses inclusiveness, robust health and safety programmes, community cohesion, environmental harmony, entrepreneurial opportunities, cultural enrichment, talent recognition, technological advances, efficient, pedestrian-friendly mobility solutions, educational investments, encouragement for creativity, connectivity, abundant green spaces and proactive climate change mitigation and adaptation measures (Caragliu and others, 2011; Nam and Pardo, 2011; Hollands, 2008; Acuto and others, 2018).

Furthermore, turning conventional cities into smart ones is not only feasible but imperative, irrespective of their age or stage of development (Ahvenniemi and others, 2017). This transformative journey necessitates a methodical approach in which each facet requiring enhancement is systematically addressed. In the case of Caxias do Sul, urban mobility emerges as a focal point for initial intervention. To gauge the quality of urban mobility in Caxias do Sul, a bespoke analytical tool was devised, leveraging insights from comparable cities such as Aarhus, which is renowned for its smart city efforts (Giffinger and others, 2007). A meticulous process of urban benchmarking and comparative analysis made it apparent that Caxias do Sul had substantial shortcomings in its urban mobility infrastructure (Albino, Berardi and Dangelico, 2015).

Addressing these deficiencies requires multifaceted interventions, encompassing not only enhanced data management and project implementation but also strategic investments in cycling infrastructure, the establishment of a bicycle-sharing programme and measures to increase the attractiveness of public transport (Deakin, Waer and Higgins, 2012). Integral to this endeavour is the development of a real-time mobility application that empowers citizens through access to critical transport information (Zhang, Gao and Mei, 2018). By making public transport and cycling more attractive while discouraging reliance on personal vehicles, Caxias do Sul stands to mitigate traffic congestion, improve air quality, enhance community inclusiveness and improve overall quality of life (Ergen and Gungor, 2014).

Proactive climate change mitigation measures also need to be integrated into Caxias do Sul's urban development agenda. This entails reducing greenhouse gas emissions through modal shifts towards sustainable forms of transport, such as cycling and public transit, and promoting energy-efficient urban design and renewable energy deployment (Acuto, Parnell and Seto, 2018). Embracing nature-based

solutions, such as an increase in urban green spaces and enhanced urban biodiversity, can bolster climate resilience and mitigate the urban heat island effect (Wamsler, Pauleit and Kaltenborn, 2020). In addition, fostering community resilience and adaptation through robust disaster preparedness and response mechanisms is essential to confront the escalating risks posed by climate change-induced extreme weather events (Pelling, O'Brien and Matyas, 2015).

However, this study is not without its limitations. The challenge of data accessibility, exacerbated by the coronavirus disease (COVID-19) pandemic, underscores the need for methodological flexibility and resilience in research efforts (Cervero and Kockelman, 1997). The pandemic also engendered uncertainties concerning its enduring impact on urban dynamics, a subject that should be explored in future studies. Potential avenues for further investigation include the pandemic's ramifications for public health, transport preparedness and broader aspects of urban resilience and sustainability (Matyas and Kamargianni, 2021).

In conclusion, while the journey towards smart city status is fraught with challenges, the concerted pursuit of incremental advances promises transformative outcomes for Caxias do Sul. By embracing a multifaceted approach to urban development, underpinned by robust governance frameworks, community engagement and proactive climate change mitigation and adaptation measures, Caxias do Sul can navigate the complexities of modern urban living and emerge as a beacon of smart city innovation, sustainability and resilience.

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