CHALLENGES AND SOLUTIONS FOR SUSTAINABLE URBAN MOBILITY: LESSONS FROM AMSTERDAM AND CURITIBA

DESAFIOS E SOLUÇÕES PARA A MOBILIDADE URBANA SUSTENTÁVEL: LIÇÕES DE AMSTERDÃ E CURITIBA

DESAFÍOS Y SOLUCIONES PARA LA MOVILIDAD URBANA SOSTENIBLE: LECCIONES DE ÁMSTERDAM Y CURITIBA

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ABSTRACT

The significance of sustainable urban mobility has become increasingly apparent, emerging as a priority in addressing contemporary environmental challenges. Frequent congestion in major urban centers, coupled with pollution from combustion-based transportation, exacerbates global warming. These challenges necessitate a reevaluation of urban transport systems and the implementation of measures that foster more sustainable and equitable mobility. Such measures include the development of dedicated cycling infrastructure and the enhancement of public transportation to increase its appeal and efficacy. This study examines sustainable urban mobility solutions in Curitiba and Amsterdam through bibliographic and descriptive research. The findings indicate that a well-planned road system can significantly reduce travel time, enhance quality of life, and alleviate the stress associated with daily transportation. Moreover, public policies that promote the use of bicycles and electric vehicles are essential in advancing sustainable mobility. The study concludes that planning measures aligned with sustainability have positive impacts on traffic flow, population well-being, and the environment.

KEYWORDS

sustainable urban mobility; cycle path; public transport; urban sustainability.

RESUMO

A importância da mobilidade urbana sustentável tem se tornado cada vez mais aparente, emergindo como uma prioridade no enfrentamento dos desafios ambientais contemporâneos. O congestionamento frequente nos principais centros urbanos, juntamente com a poluição do transporte baseado em combustão, agrava o aquecimento global. Esses desafios exigem uma reavaliação dos sistemas de transporte urbano e a implementação de medidas que promovam uma mobilidade mais sustentável e equitativa. Essas medidas incluem o desenvolvimento de infraestrutura dedicada ao ciclismo e o aprimoramento do transporte público para aumentar seu apelo e eficácia. Este estudo examina soluções de mobilidade urbana sustentável em Curitiba e Amsterdã por meio de pesquisa bibliográfica e descritiva. As descobertas indicam que um sistema viário bem planejado pode reduzir significativamente o tempo de viagem, melhorar a qualidade de vida e aliviar o estresse associado ao transporte diário. Além disso, políticas públicas que promovam o uso de bicicletas e

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veículos elétricos são essenciais para o avanço da mobilidade sustentável. O estudo conclui que medidas de planejamento alinhadas à sustentabilidade têm impactos positivos no fluxo de tráfego, no bem-estar da população e no meio ambiente.

PALAVRAS-CHAVE
Mobilidade urbana sustentável; ciclovia; transporte público; sustentabilidade urbana.

RESUMEN
La importancia de la movilidad urbana sostenible se ha vuelto cada vez más evidente, emergiendo como una prioridad en la lucha contra los desafíos ambientales contemporáneos. La congestión frecuente en los principales centros urbanos, junto con la contaminación generada por el transporte basado en combustión, agrava el calentamiento global. Estos desafíos exigen una reevaluación de los sistemas de transporte urbano y la implementación de medidas que promuevan una movilidad más sostenible y equitativa. Estas medidas incluyen el desarrollo de infraestructuras dedicadas al ciclismo y la mejora del transporte público para aumentar su atractivo y eficacia. Este estudio examina soluciones de movilidad urbana sostenible en Curitiba y Ámsterdam a través de una investigación bibliográfica y descriptiva. Los hallazgos indican que un sistema viario bien planificado puede reducir significativamente el tiempo de desplazamiento, mejorar la calidad de vida y aliviar el estrés asociado al transporte diario. Además, las políticas públicas que promueven el uso de bicicletas y vehículos eléctricos son esenciales para el avance de la movilidad sostenible. El estudio concluye que las medidas de planificación alineadas con la sostenibilidad tienen impactos positivos en el flujo del tráfico, el bienestar de la población y el medio ambiente.

PALABRAS CLAVE
Movilidad urbana sostenible; carril bici; transporte público; sostenibilidad urbana.

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1. INTRODUCTION

Sustainability in transportation entails meeting mobility needs while considering environmental impacts and maintaining human quality of life. According to Carvalho (2011), the transportation of people and goods in urban centers is invariably linked to pollution—whether atmospheric, noise, or visual—regardless of the mode used. Sustainable mobility encompasses travel methods that minimize negative impacts on the environment, society, and the economy. This includes promoting the use of efficient public transportation, electric vehicles, active mobility, and smart urban planning, alongside technologies designed to reduce congestion and pollution.

The growing demand for electric vehicles (EVs) has sparked discussions about their actual sustainability, primarily due to the use of lithium batteries. Overall, recent global literature reviews conclude that EVs contribute to reducing greenhouse gas emissions and offer lower operational costs (Das; Bhat; Sajith, 2024; Verma; Dwivedi; Verma, 2022). However, other environmental aspects, such as resource extraction and human toxicity levels, must be considered. Battery production requires the extraction of manganese, cobalt, nickel, and graphite, which poses significant environmental harm (Das, Bhat; Sajith, 2024). Furthermore, the increased use of metals, chemicals, and energy in lithium batteries heightens human toxicity risks (Verma, Dwivedi; Verma, 2022). Therefore, further research is necessary to assess these long-term environmental impacts. Additionally, the recyclability of batteries remains a limiting factor in developing countries, as there is a limited number of companies worldwide capable of recycling these materials effectively.

Despite significant advances over the last few decades, the quest for sustainable urban mobility continues to face persistent challenges. According to Carvalho (2016), the increase in the use of individual transportation presents considerable difficulties for public managers concerning urban planning and the efficient management of mobility in cities. Ferreira (2015) points out that large cities, under past administrations, should have emphasized urban planning. By focusing solely on economic development, these administrations inadvertently caused a series of urban infrastructure problems, such as flooding due to soil impermeabilization and the removal of native vegetation. Therefore, it becomes a challenge for public managers and leaders to plan and mitigate these negative consequences. It is incumbent upon them to incorporate the concept of sustainable development into their planning efforts.

At the international level, it is recognized that excessive dependence on individual vehicles, over-occupation of territories, and a large ecological footprint significantly impact sustainable urban mobility (Ortúzar, 2019). Consequently, Lam and Head (2012) discuss several strategies, including integrated urban planning and design, the expansion of ecological vehicles, the promotion of changes in habits, and the implementation of low CO_2 emission policies.

According to Ortúzar (2019), the rise in congestion is a consequence of the increasing use of individual vehicles, which adversely affects public transportation. This situation is further exacerbated by population growth in segregated urban peripheral areas. These combined factors lead to a decrease in the efficiency of public transport services, rendering cars a more attractive option.

In Europe, public measures have been considered to reduce the use of individual transport by incentivizing employees to adopt more sustainable means of transportation. In Belgium, a study conducted by Van Malderen et al. (2012) examined the role of organizations in promoting sustainable mobility by implementing policies aimed at encouraging the use of bicycles, public transport, and carpooling. To motivate employees to adopt sustainable modes of transport, organizations must offer additional financial incentives, provide facilities such as bike racks and showers, and disseminate information on cycling routes and public transport timetables.

Through a case study of Curitiba and Amsterdam, this article aims to provide valuable insights into the aspects of sustainable urban mobility in these cities, which serve as benchmarks in Brazil and globally. The study will address the benefits and challenges encountered in implementing sustainable mobility plans. Moreover, it will serve as a foundation for reflections on the future of large cities in their pursuit of sustainability.

2. METHODOLOGY

This research was structured based on methodological procedures designed to align and discuss sustainable urban mobility interventions, with a focus on their application in Curitiba, Brazil, a city of national significance in this regard, and Amsterdam, a global benchmark in sustainable mobility.

This study is exploratory and descriptive, involving the understanding and interpretation of bibliographic information sourced from articles, books, dissertations, and government documents (Gil, 2010). Consequently, it is characterized as a case study due to its specific focus on Curitiba, Brazil, and Amsterdam.

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Based on the literature reviewed, this study aims to evaluate the guidelines adopted by the management of these municipalities to pursuit sustainable urban mobility. It compares the strategies employed in two cities with distinct technical, economic and structural realities.

3. RESULTS AND DISCUSSION

3.1 Curitiba

Curitiba gained prominence for its urban solutions, albeit in a distinct manner. Rather than pursuing artificial transformation, the city adapted its growth to the rationalization of public space, utilizing planning as a catalyst for development (Gnoato, 2006). The major transformation in Curitiba was driven by the Preliminary Urban Planning Plan of 1965 (Gnoato, 2006). This plan sought to deviate from the extensive urban reforms applied in cities like São Paulo, exemplified by the Prestes Maia Plan, which introduced bridges and viaducts, or the cold and inhumane model proposed by the modernist precepts of the Athens Charter, as seen in Brasília. The principal architect behind this plan was Jorge Wilheim, who collaborated with a group of young technicians who would later become significant figures in the Brazilian urban scene, such as Luiz Forte Netto, Jaime Lerner, José Maria Gandolfi, Alfred Willer, among others. These individuals were also instrumental in founding the Architecture and Urban Planning course at the Federal University of Paraná. According to Miranda (2010), Curitiba transformed the preliminary version of this plan into law in 1966 with the approval of Municipal Law No. 2,828, just one year after its conception. Additionally, the city established an important urban planning and design body: the Curitiba Urban Research and Project Institute (IPPUC).

The significant urban transformations in Curitiba began with the inauguration of Jaime Lerner as mayor in 1971 (IPPUC, 2009). This period marked a departure from the mistakes of modernist urbanism, such as the segregation of the urban fabric based on activities, as recommended by the concept of functional spaces by Le Corbusier (Choay, 2007). The influence of Jane Jacobs' urban theories was clearly evident in the urbanism concepts adopted in Curitiba. According to Jacobs' perspective, the safety of an area is directly linked to the variety of functions it supports, as the constant presence of users and observers on active streets fosters natural community surveillance (Jacobs, 2007). This suggests that diverse functions should coexist, attracting people throughout the day. Consequently, the city's urban planners concentrated their efforts on revitalizing existing streets, ensuring they remained vibrant all day long (Gnoato, 2006).

Wilheim's initial plan, continued by Lerner, was based on a crucial tripod: land use, public transport, and circulation (IPPUC, 2009). Following this model, new zoning legislation enacted in 1975 considered land use and its implications (use coefficient and building height), in conjunction with the concepts of Structural Axes and the public transport system (Gnoato, 2006). This approach enabled Curitiba to achieve significant political success and, with the continuity of the same team of urban planners at IPPUC, ensured the successful implementation of its plan across multiple administrations (Miranda, 2010).

The Structural Axes (Figure 1) led to the development of the trinary system, which consists of a set of three roads. The central road is designated for slow traffic, accommodating the public transport corridor and local commerce, while the outer roads are intended for fast traffic and are known as "Fast Lanes" (Miranda, 2010).

Figure 1: Structural Axes.
Source: PlanMob Curitiba, IPPUC, 2008. Adapted.

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According to Miranda (2010), the Structural Axes represent the classic urban design developed in Curitiba. The city's zoning was established based on the distance different regions maintain from these key growth and population density references. Consequently, building heights are staggered, being taller along the axes and decreasing as one moves away from them. In addition to the changes introduced by land use and occupation laws, Curitiba designated a significant portion of its central area exclusively for pedestrian circulation through the implementation of sidewalks (Figure 2).

The Street XV Promenade became the symbol of this new urban planning, with the preferential pedestrian routes marking a milestone in the transformation experienced by the city in the early 1970s (IPPUC, 2008). The intense pedestrian circulation revitalized these spaces, attracting entertainment activities for the population, such as fairs and open-air cultural events.

Figure 2: XV Street Promenade.
Source: CNB Curitiba, 2022.

Another crucial aspect of Curitiba's mobility plan is the evolution of the public transport system between 1970 and 2009, which exhibited significant variations in operational aspects and demand. The length of the network increased from 53 km to 81.4 km, representing a 54% expansion. This growth enhanced the system's capillarity, improving accessibility for urban travel. Concurrently, the bus fleet expanded from 826 to 1,911 vehicles, with a substantial increase in passenger capacity due to the introduction of larger vehicles. Initially, passenger demand increased, peaking at 2.4 million daily passengers in 2008, but then began to decline, falling to 2.3 million within the same year—a reduction of 9%—and continuing a downward trend to 2.2 million by 2014 (Vasconcellos, 2019). The latest data released by Urbanization of Curitiba (URBS, 2022) indicates that daily public transportation usage stands at approximately 1.1 million, reflecting a sharp 50% decline over just eight years.

The population increased significantly during this period. Therefore, it is crucial to estimate the general demand per inhabitant of the metropolitan area to reflect the transport system's attractiveness to the population. In 2004, the rate of daily trips per inhabitant on the metropolitan bus network was 0.77, but this rate began to decline, reaching 0.64 in 2014, a drop of 17%. The value recorded in 2016, 0.43, can be considered extraordinary due to the economic crisis that affected the country, significantly impacting the use of public transport (IPPUC, 2010; Vasconcellos, 2019). The latest 2022 data shows a daily trip rate of only 0.29 (URBS, 2022).

According to Vasconcellos (2019), several hypotheses can explain the decrease in public transport use. In a city with a relatively high income by Brazilian standards, the first hypothesis considers the increase in the fleet of individual cars. Indeed, the rate of cars per hundred inhabitants increased from 22 to 60 (172%) between 1970 and 2009, reaching 77 in 2023, according to DETRAN-PR (2023). A second factor may be related to low-income individuals who struggle to afford the fare. The burden of the fare on the minimum wage, which is received by most low-income people, increased from 6.4% in the first decade to 23.7% in the last decade.

Despite the decline in the use of public transport, these means of transport still have several significant advantages. According to Miranda (2010), several characteristics were adopted to improve the efficiency and quality of public transport. These characteristics include metropolitan coverage, which allows public transport to cover a wide area of the city and its surroundings. Furthermore, a single-fee payment system was implemented, which facilitates user access and simplifies the payment process. The buses were differentiated through a typology of services with different colors, which helps users to easily identify the different lines and their routes. The public transport system also has 72 km of dedicated channels, roads and lanes, which allow buses to circulate more quickly and efficiently, avoiding congestion typical of roads shared with private vehicles.

Regarding bus terminals, they are classified into different types according to their location and function within the road system. These types include tip terminals, which are the endpoints of certain lines; intermediate terminals, which serve as transfer points between different lines; neighborhood terminals, which serve specific areas within neighborhoods; central area terminals, which

facilitate access to the city center; and metropolitan terminals, which connect the city with peripheral areas and other nearby cities. This classification, as illustrated in Figure 3, is fundamental for the proper functioning and organization of the public transport system.

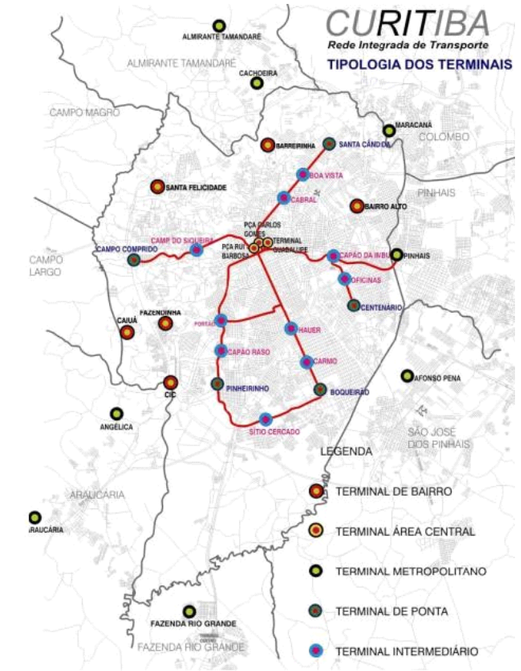

Figure 3: Terminal typology
Source: Miranda, 2010.

The Green Line is also notable (Fig 4), developed based on Law 13,909/2011. This initiative establishes guidelines in the area influenced by BR-116, which traverses Curitiba in the northeast-southeast direction. It encompasses a series of interventions by municipal public authorities, funded by the sale of certificates of additional construction potential (Locatelli, Bernardinis, & Moraes, 2020).

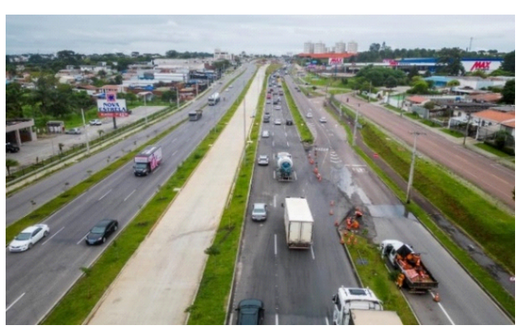

Figure 4: Green Line, Curitiba.
Source: Miranda, 2010.

Another notable implementation is the concession of electric public transport. According to the City of Curitiba, the first tests with electric buses and taxis were conducted in 2023, involving 70 vehicles that will become part of the 2024 fleet. This marks the beginning of the decarbonization of the public transport fleet, establishing one of the pillars of sustainability for the municipality. These measures align with Curitiba's commitment to consolidating public policies aimed at climate change, with transformative and inclusive actions to enhance climate resilience, in accordance with the objectives of the Paris Agreement and the 2030 Agenda for Sustainable Development (SDGs) (City of Curitiba, 2023).

The city of Curitiba was the first in the country to conduct tests of electric buses from brands such as BYD, Volvo, Eletra, and Marcopolo. The results indicated zero emissions, quiet operation, and air-conditioned comfort, which were well-received by users who participated in quality tests (Prefeitura de Curitiba, 2023). Thus, it can be concluded that Curitiba's urban mobility planning was comprehensively designed to prioritize public transport. This involved promoting exclusive routes throughout the city, aiming to enhance efficiency and consequently encourage the population to utilize public transport.

3.2 Amsterdam

Over the last century, the primary mobility planning challenge in the Netherlands has been to develop an adequate railway system connecting the country's secondary centers to the "mother city" of Amsterdam, followed by establishing road connections. Years later, with the expansion of activities in intermediate zones, the challenge shifted to developing a regional transit system through road hierarchization. This approach allows different cities to function as complementary centers, as illustrated in Figure 5 (Bertolini & Le Clercq, 2003).

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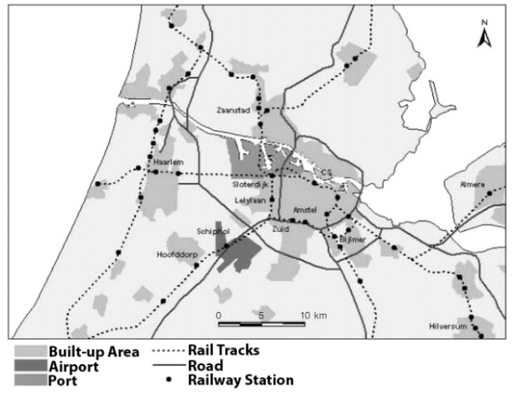

Figure 5: Amsterdam Road System and Subcenters.
Source: Bertolini; Le Clercq, 2003. Adapted.

According to Bersan (2023), in 1978, the government implemented the Traffic Circulation Plan, an initiative that transformed Amsterdam into a more welcoming city for cyclists. Space allocated to large vehicles was reduced and reallocated to create cycle paths and common areas for pedestrians, as illustrated in Figures 6 and 7, showing the before and after. This initiative significantly improved the infrastructure for bicycle traffic throughout the city.

Figure 6: Damrak Avenue in the 1970s and 2010s.
Source: ArchDaily, 2023.

Figure 7: Currently preferred street for cyclists.
Source: Tarantino, 2023.

In the 1980s, the Netherlands implemented significant traffic measures aimed at promoting safer and more sustainable urban mobility. These measures included introducing new signage, expanding the cycle path network, imposing strict speed limits, installing speed bumps, increasing parking prices in city centers, and reducing road sizes to discourage high-speed driving and the use of individual vehicles. Cities such as The Hague and Tilburg were pioneers in adopting red-painted cycle paths to ensure high visibility, an innovative approach at the time (Bersan, 2023).

In addition to these measures, the most effective approach has been the creation of extensive networks of cycle paths, totaling approximately 35,000 kilometers in the Netherlands, reaching 815 km in Amsterdam (Government of the Netherlands, 2024; European Union's Horizon, 2024). The habit of cycling was already ingrained in local culture long before congestion problems arose, leading around 40% of the population to choose this mode of transport for their daily commute. The country's flat topography further favors the use of bicycles. Moreover, there is a licensing system for cyclists, available to individuals over 12 years of age, which imposes fines on those who disregard traffic rules (Denardi et al., 2011).

In the central region of Amsterdam, trams are the primary means of public transport. They operate on rails and are powered by electricity through overhead cables along the streets. Despite their effectiveness, trams pose challenges for the city's numerous cyclists, who must be cautious to prevent their wheels from getting caught on the tracks that cross many streets (Denardi et al., 2011).

A policy implemented not only in Amsterdam but throughout the Netherlands is the introduction of a Corporate Mobility Management (CMM) system. This system, aimed at companies with more than fifty employees, seeks to effectively improve employee mobility by offering measures to reduce the use of private vehicles. In 1989, when concerns about urban mobility began to emerge in the Netherlands, Novem, a Dutch company specializing in energy and the environment, conducted a survey involving 16,000 companies regarding the CMM. The survey revealed that 30% of these companies had some knowledge about the system, and only 6% had implemented it. Among the companies that adopted the CMM, there was an 8% reduction in the use of private vehicles by employees (Denardi et al., 2011).

Recently, a new law in the Netherlands mandates that, starting July 1, 2024, companies with more than 100 employees must report annually on business travel and employee commuting. The law requires companies to

restrict parking access to employees commuting more than 15 km, provide public transportation passes without payroll tax deductions, encourage train use for business travel, offer incentives for purchasing or leasing company bicycles, and promote remote work (KVK & RVO, 2024). Thus, the law aims to strengthen corporate engagement with sustainable urban mobility policies.

The authors further explain that, in addition to the previously mentioned strategies, the Dutch Ministry of Transport announced in 2012 the implementation of a fee per kilometer driven as a means to combat urban congestion. From that year onwards, all cars circulating in the country were charged three euro cents per kilometer, with adjustments continuing until 2017. In areas and during times of heavy traffic, the tariff would be higher. Highly efficient vehicles, such as hybrids, would receive a reduced rate. To compensate for this new tariff, vehicle taxes would be reduced. By 2012, all cars were required to be equipped with GPS devices, under penalty of fine, to transmit movement information to the Fare Collection Center. The receptivity of Dutch culture to change was crucial for the government's implementation of these measures, facilitating their acceptance (Denardi et al., 2011).

According to Knorek (2019), cycle paths and lanes dedicated to bicycles are prominent features of Amsterdam. Due to its geographical configuration, the city has many canals that facilitate urban mobility, used by both tourists and local residents. Amsterdam also has numerous ferries and boats that transport people and products around the city, integrating into the logistics of urban mobility. Consequently, it is concluded that urban mobility in Amsterdam is primarily due to the various modes of transport supported by public policies that were introduced to further encourage the population to utilize more sustainable forms of transport, especially bicycles, which are already an integral part of daily life. This, in turn, reduces the emission of polluting gases into the atmosphere.

3.3 Challenges

The comparison between Curitiba and Amsterdam in sustainable urban mobility reveals significant differences shaped by their contexts as a developing and developed country, as well as their topography and climate.

In Curitiba, the focus has been on developing an innovative public transportation system, highlighted by bi-articulated buses operating on exclusive corridors. However, increased use of private vehicles, fare pressures on low-income users, and declining public transportation demand pose significant challenges. Recent fleet electrification initiatives demonstrate a commitment to sustainability, but overcoming cultural resistance to abandoning individual transportation and securing continuous funding remain critical challenges for the future.

Amsterdam has pursued an integrated approach, establishing the bicycle as the primary mode of urban transportation, complemented by trains, trams, and boats. Its extensive cycling infrastructure, along with policies restricting car use, has fostered a low-carbon environment. Furthermore, favorable topography and relatively mild annual temperatures have been key factors in the successful consolidation of bicycle use in both Amsterdam and the Netherlands.

Thus, public policies play a fundamental role in implementing sustainable urban mobility practices, but the consolidation of certain modes, such as cycling, is often constrained by physical and climatic conditions, posing a barrier in many cities and countries—not exclusively in Brazil.

4. CONCLUSION

Sustainable urban mobility is an increasing priority for cities worldwide, with Curitiba and Amsterdam serving as illustrative cases of distinct yet effective strategies. Curitiba's focus on an innovative public transportation system—exemplified by bi-articulated buses on exclusive corridors—demonstrates how infrastructure tailored to local needs can optimize mobility. In contrast, Amsterdam's emphasis on integrating cycling with public transport, supported by an extensive network of paths and complementary trams, trains, and buses, showcases how multimodal systems can drive sustainable mobility and significantly reduce car dependency.

Both cities exemplify that there is no universal formula for sustainable urban mobility; rather, success depends on aligning policies with the social, geographic, and climatic realities of each location. Their experiences highlight the importance of flexibility in policy-making, where investments in public transportation, incentives for active mobility, and car-use restrictions work in tandem to foster sustainable environments.

Ultimately, Curitiba and Amsterdam provide transferable insights that can inspire other cities, adapting solutions to their unique contexts. These examples underscore that sustainable urban mobility is not merely about reducing emissions but about creating efficient, livable cities that prioritize accessibility, environmental responsibility, and the well-being of their citizens.

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