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Review paper

IMPLEMENTATION OF SUSTAINABLE TRANSPORT MODELS IN INNOVATIVE AND ENVIRONMENTALLY FRIENDLY URBAN ENVIRONMENTS THROUGH ANALYSIS OF COPENHAGEN AND PARIS

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Abstract

Rapid urbanization and population growth create significant challenges in the field of transport, especially in the context of sustainability and environmental friendliness. Modern cities face increasingly serious problems of pollution, traffic congestion and excessive energy consumption, which further exacerbate the impact on climate change. In order to ensure the long-term sustainability of urban environments, it is necessary to adopt innovative transport models that reduce pollution, optimize mobility and increase the resilience of cities to environmental challenges. The paper explores innovative approaches in the planning and implementation of sustainable transport systems, with a particular emphasis on the integration of public transport, the development of cycling and pedestrian corridors, as well as the use of smart technologies to improve transport. Concepts such as "smart cities" and "15-minute cities" will be analyzed, which enable efficient and environmentally friendly population movement. The comparative analysis method will present examples of cities that have successfully implemented sustainable transport solutions, such as Copenhagen and Paris, in order to identify best practices and opportunities for application in different urban environments. Through this analysis, the aim is to highlight the importance of sustainable transport as a key factor in reducing pollution, improving the quality of life of citizens and building dynamic, resilient and more environmentally friendly cities of the future.

Key words: *Sustainable transport, Smart cities, 15-minute cities, Sustainable development, Climate change*

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1. INTRODUCTION

Contemporary urban environments stand at a crossroads, facing the growing demand for space and the necessity for adaptable, sustainable solutions in response to rapid urbanization and technological advancement. Traditional transport models, primarily based on the individual use of motor vehicles, contribute to excessive air pollution, climate change, traffic congestion, noise, degradation of public spaces, and a general decline in the quality of life in urban areas. In this context, sustainable transport models are gaining increasing importance as societies around the world become more aware of the negative impacts of conventional transportation methods on the environment and public health. The primary goal of these models is to provide reliable, energy-efficient, and affordable transport solutions while minimizing adverse effects on ecosystems. In addition to reducing greenhouse gas emissions, sustainable transport models also promote physical activity, healthier lifestyles, and greater social inclusion.

Modern concepts such as smart cities and 15-minute cities represent innovative approaches to urban planning that encourage improved spatial and transport structures, where everyday needs can be met within short distances. In this context, sustainable transport refers to green, energy-efficient, and accessible modes of mobility with minimal environmental impact, such as walking, cycling, public transit, electric and hybrid vehicles, as well as alternative fuel-powered transportation. The overall sustainability of a transport system is evaluated based on the efficiency of its components, their environmental and climate impacts, and the structure and functionality of infrastructure (roads, railways, terminals, etc.). Data indicate that transport systems account for approximately 20% to 25% of global energy consumption and CO_2 emissions [1]. At the same time, transport remains a vital driver of economic development and human mobility, making the adoption of sustainable transport models not only an ecological but also a socio-economic imperative for all urban communities striving toward a better future.

The subject of this research is the analysis of sustainable transport models and their implementation in innovative and environmentally adaptive urban settings, with a particular focus on the integration of public transportation, bicycle and pedestrian corridors, and smart technologies within transport infrastructure. The aim of the study is to highlight, based on an analysis of best practice examples, specific models and strategies that enhance sustainability in urban environments. Special attention is given to identifying the key success factors in cities that have achieved significant progress in this area, as well as the potential applicability of these principles in other urban contexts. The research methods employed in the paper include data collection, data analysis, descriptive method, comparative analysis and synthesis, as well as the inductive–deductive method to formulate conclusions based on concrete examples.

2. CONCEPT AND PRINCIPLES OF SUSTAINABLE TRANSPORT MODELS

Sustainable transport models represent a systemic approach to the planning, organization, and improvement of transport infrastructure and services, with the aim of meeting mobility needs in an environmentally friendly, socially equitable, and economically efficient manner [2]. Sustainable transport seeks to fulfill transportation needs while

preserving human health and ecological balance by utilizing renewable resources at a rate that does not exceed their natural regeneration and using non-renewable resources at levels below the development rate of renewable alternatives.

A sustainable transport system is defined as one that: enables the safe fulfillment of individual and societal transportation needs without compromising human health or ecosystems, while respecting the principle of equity both within and between generations; ensures economic accessibility and efficiency, provides a diversity of transport modes, and supports the flexibility of modern economies; reduces emissions and waste within the planet's ecological capacity, minimizes the use of non-renewable energy sources, and controls the consumption of renewables within sustainable limits; applies principles of recycling and reuse of its components, while minimizing land use and noise pollution [3].

Key characteristics of sustainable transport systems include: reducing harmful emissions and air pollution through a shift to electric vehicles, cycling, and walking; promoting public transportation as the primary mode of mobility, with improved frequency, reliability, and accessibility; integrated planning of transport and urban development to align mobility with spatial organization; multimodality, i.e., the ability to seamlessly switch between different modes of transport without loss of time or comfort; social inclusivity, ensuring equal access to transport services for all population groups; and energy efficiency through reduced fossil fuel consumption and support for renewable energy sources [3].

Sustainable transport aims to meet society's current mobility needs without compromising the ability of future generations to meet theirs. The concept is based on the application of environmentally sound technologies, alternative fuels (such as electricity, gas, and biodiesel), and the development of intelligent transport systems (Fig.1) [4].

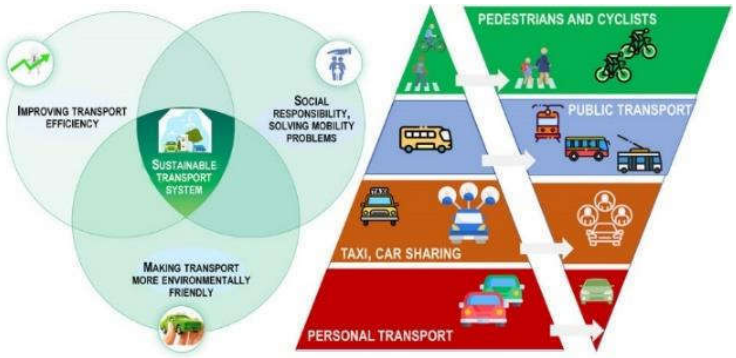

Figure 1. Goals and ways towards sustainable transport, https://www.frontiersin.org/journals/built-environment/articles/10.3389/fbuil.2023.1161361/full

Contemporary concepts such as smart cities, which rely on digital technologies for more efficient traffic management, and 15-minute cities, where all essential services are available within a short walking or cycling distance, are significant tools for building sustainable transport systems. The idea of sustainable transport is closely linked to the notion of intergenerational justice, which implies that the needs of present generations should not be met at the expense of future ones.

3. GOOD PRACTICE EXAMPLES

The successful implementation of sustainable transport models in various cities around the world demonstrates the potential of such approaches to transform urban environments toward ecological resilience, energy efficiency, and improved quality of life. Among the most prominent examples are Copenhagen and Paris, which represent two distinct yet equally inspiring models of urban mobility—one based on a long-standing culture of cycling, and the other on a comprehensive transformation aligned with the concept of the "15-minute city." In addition to these examples, numerous other cities around the world have demonstrated significant progress in implementing sustainable transport solutions:

- Amsterdam, Netherlands – A city where bicycles dominate daily transportation, supported by outstanding cycling infrastructure and a strong cycling culture
- Tokyo, Japan – Renowned for having one of the most advanced public transportation systems globally, alongside a growing number of electric vehicles
- Stockholm, Sweden – An example of a city utilizing biofuels in public transport and maintaining an extensive network of bicycle and pedestrian paths
- Portland, USA – Known for actively promoting cycling, electric vehicles, and sustainable urban planning practices
- Zurich, Switzerland – A model of efficient, integrated public transport, with strong measures aimed at reducing pollution, noise, and energy consumption

3.1. City of Copenhagen

Copenhagen, as the capital of Denmark, has for decades been committed to improving the quality of life for its residents through the integration of environmentally responsible transport, urban planning, and advanced technological solutions. The city implements multiple models of sustainable transport that together form a functional, ecological, and inclusive mobility system:

- Public transport powered by renewable energy – The city employs electric and biogas-powered buses, as well as metro systems running on green energy
- Integrated cycling system – With more than 400 km of dedicated cycling lanes, special bridges for cyclists, bicycle "highways," and bike-sharing schemes, cycling has become the dominant mode of transport [5]
- Green pedestrian zones and urban planning – The promotion of walkability and traffic-free public spaces, with a strong focus on safety and accessibility
- Car-sharing and micromobility – A well-developed network of shared electric vehicles, e-scooters, and bicycles
- Reduction of car traffic – High parking fees, restricted access to the city center, and planning mechanisms that prioritize public transportation and cyclists [5].

The smart city concept encompasses the use of information and communication technologies (ICT) and innovations in urban governance to improve quality of life, reduce resource consumption, and enhance public services [6]. Copenhagen is a leading example in this domain, with a model that includes:

- Sensor networks for monitoring pollution, noise, and traffic – Data are used in real time to optimize traffic flow and plan urban interventions
- Smart lighting and energy systems – Devices that automatically respond to environmental conditions to reduce energy consumption

- Open Data platform – Public access to city data encourages innovation, transparency, and citizen participation
- Smart mobility – Applications that integrate real-time information on all modes of transport, enabling more efficient travel planning for citizens.

One of the most striking features of Copenhagen is its well-developed cycling culture (*Fig. 2a*). The city boasts over 400 kilometers of specially marked and physically separated bike lanes, as well as several bridges dedicated exclusively to pedestrians and cyclists, such as the famous Cykelslangen - The Bicycle Snake (*Fig. 2b*). The so-called "super bicycle highways" connect Copenhagen with neighboring municipalities, promoting intercity mobility without reliance on cars [7].

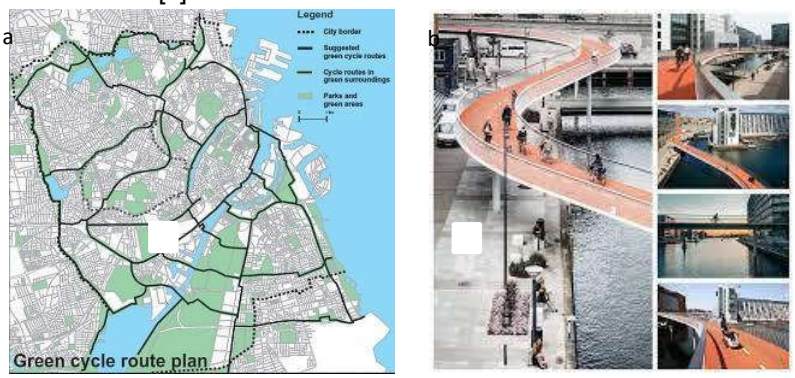

Figure 2a - Green cycle route plan of Copenhagen and 2b - Bridge Cykelslangen - The Bicycle Snake bridge https://www.slideshare.net/slideshow/sustainable-transport-system-of-copenhagen-citypdf/266559943

3.2. City of Paris

Paris is one of the most prominent examples of a European metropolis that systematically implements innovative and sustainable transport models. The city is investing substantial resources in ecological transition and reducing dependence on private vehicles, with the aim of improving quality of life and combating climate change [8].

Sustainable transport models implemented in Paris include:

- Public transport powered by electric and hybrid energy – The Paris metro system, one of the most advanced in the world, increasingly relies on electric and energy-efficient trains. The bus system is also undergoing gradual electrification, with a goal to achieve a mostly zero-emission fleet by 2030
- Cycling infrastructure – Paris has significantly expanded its network of bike lanes through the "Plan Vélo" program. Many streets have been redesigned to prioritize cyclists and pedestrians. The Vélib' public bike-sharing system is one of the largest in Europe, with over 20,000 bicycles, a large portion of which are electrically assisted
- Pedestrian zones – The city center is progressively becoming a car-free zone. A notable example is the transformation of the Seine riverbanks into public pedestrian spaces, closed to motorized traffic
- Electric and shared vehicles (car-sharing) – Paris supports the expansion of electric vehicles through a dense network of charging stations and services such as Autolib' and Zity that offer electric car-sharing options

- Micromobility – Electric scooters, small electric motorcycles, and similar vehicles are regulated under sustainable mobility policies and integrated into the broader transportation system

Paris is also developing the smart city concept through the adoption of digital tools and systems that enhance urban efficiency, transparency, and environmental sustainability. Through the "Paris Smart City 2050" platform, the city integrates innovations in energy efficiency, resource management, and urban mobility [9]. The use of smart lighting that adapts automatically, digital signage, and real-time air quality and traffic monitoring systems enable better control of urban processes and reduce energy consumption. Interactive applications provide citizens with information on public transport arrival times, traffic conditions, air pollution levels, and parking availability. The city actively involves citizens in decision-making through digital participatory platforms, a fundamental feature of smart and democratic urban communities.

The 15-minute city is an urban planning concept that promotes the idea that all residents should be able to access essential services—such as work, education, healthcare, recreation, and shopping—within a 15-minute walk or bike ride from their home (Fig. 3a). The concept, developed by Professor Carlos Moreno, has been adopted by the Mayor of Paris as a core element of the city's sustainable urban development agenda [10].

The goal of this approach is to reduce the need for long commutes and automobile reliance, increase social interaction, boost the local economy, and enhance overall quality of life. In practice, it involves redistributing urban functions, increasing the presence of public and community facilities across all neighborhoods, redesigning streets to favor pedestrians and cyclists, and introducing multipurpose facilities (e.g., schools that function as cultural or sports centers in the afternoons) [11].

By applying the 15-minute city concept, Paris aims to decentralize urban services, reduce traffic congestion, improve public health, increase energy efficiency, and encourage local communities to play a more active and responsible role in city life. This model of urban development is already showing results in Paris and is inspiring other cities around the world seeking to combine urban compactness, social equity, and environmental sustainability (Fig. 3b).

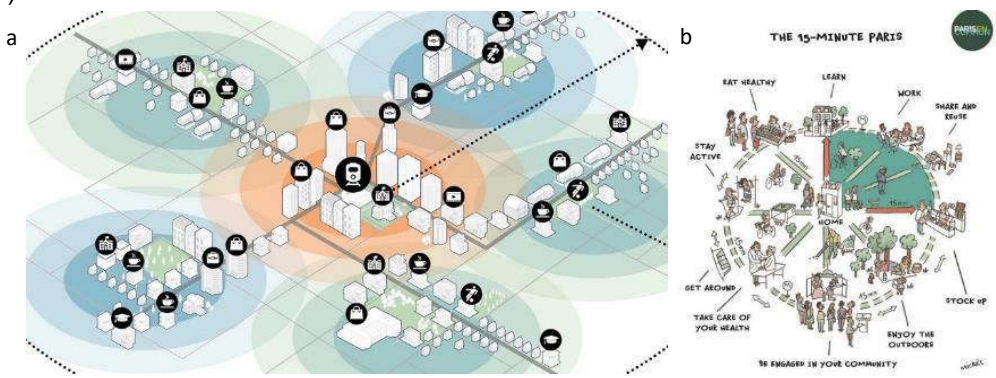

Figure 3a - The concept of the 15-minute city and 3b - Paris as a 15-minute city, https://resistire-project.eu/better-stories/paris-as-a-15-minute-city/

3.3. Comparative Analysis of Urban Sustainable Transport Strategies in Copenhagen and Paris

In order to better understand how different cities address the challenges of urban mobility, it is particularly important to compare the strategies and outcomes in cities that lead in the implementation of sustainable transport models (*Table 1*). Paris and Copenhagen represent two distinct but successful approaches to urban development—one based on a decades-long cycling culture and technological innovation, and the other on the integration of the "15-minute city" concept.

Table 1. Comparative Analysis of UST Strategies in Copenhagen and Paris

Criteria	Copenhagen	Paris
Main Strategy	"City for Cyclists"	"15-Minute City"
Public Transport	High-quality metro and bus network with electric buses	Metro, buses, and trams – electrification in progress
Cycling Infrastructure	400 km of lanes; mandatory cycling planning	Expanded network of lanes; Vélib' public bike system
Pedestrian Zones	Numerous streets prioritized for pedestrians and cyclists; low-motorized city center	Central areas closed to traffic; Seine riverbanks turned into pedestrian spaces
Electric and Shared Vehicles	Support for EVs and car-sharing, though to a lesser extent than Paris	Developed charging network; systems like Autolib' and Zity
Citizen Participation in Planning	Moderately high; inclusion through community dialogues and city workshops	High; participatory budgeting and platforms for citizen proposals
Smart Technologies	Smart traffic management, IoT devices, intersection sensors	Digital panels, apps, air quality and traffic monitoring

4. IMPLEMENTATION OF SUSTAINABLE TRANSPORT MODELS

The implementation of sustainable transport models in urban environments represents a complex and long-term process that requires coordination among various stakeholders, as well as the application of innovative technologies and principles of urban planning. The primary goal of this process is to create transport systems that reduce negative environmental impacts, improve the quality of life for citizens, promote economic development, and ensure social equity in mobility.

The adaptability of urban environments to ecological challenges involves implementing measures that not only mitigate the effects of climate change but also promote the role of transport in preserving the environment. Transport systems can be adapted to ecological challenges through various strategies, such as:

- Green infrastructure: the development of public transport networks that utilize environmentally friendly energy sources, such as electric buses or trains, as well as the creation of cycling and pedestrian zones
- Urban zone adaptation: planning cities in such a way that most essential services are accessible by walking or cycling, thereby reducing car dependency and lowering pollution levels
- Rehabilitation of vulnerable areas: transforming former industrial zones into green and urban parks that support biodiversity and improve air quality [3].

The task of urban planners and city authorities is to design transport strategies that simultaneously address traffic congestion and pollution, while also preparing cities for future climate challenges [12].

Technological innovations are playing an increasingly important role in creating sustainable and environmentally adaptive transport solutions. The integration of smart technologies into transport systems enables improved efficiency, safety, and sustainability, while also reducing negative environmental impacts.

Key technological innovations contributing to transport sustainability include:

- Electric and hybrid transport: the increased use of electric cars, electric bicycles, and public transport powered by clean energy significantly reduces CO_2 emissions
- Autonomous vehicles: self-driving vehicles using optimized algorithms for navigating cities can significantly reduce traffic congestion and energy consumption, as they operate according to real-time needs and pre-defined routes
- Traffic management systems: smart systems that leverage big data and the Internet of Things (IoT) enable better traffic flow and improved public transport management, thereby reducing delays and energy usage
- Green and smart charging stations: the development of electric vehicle charging infrastructure that integrates solar panels and other renewable energy sources allows for energy savings and CO_2 emission reduction

By applying these innovations, cities can significantly improve their transport systems, making them more efficient and environmentally friendly, while also creating new opportunities for local economic development and employment in the technology sector [4].

5. CONCLUDING CONSIDERATIONS

The implementation of sustainable transport models in urban environments is not merely a necessity, but a responsibility in the face of climate change, urbanization, and the social challenges confronting contemporary cities. Sustainable transport represents not only a technical challenge but also a social and political process that demands the cooperation of multiple stakeholders including local governments, urban planners, engineers, and citizens as active participants in the transformation of urban space [4]. Based on the analysis of best practice examples from Copenhagen and Paris, it can be concluded that successful implementation requires a comprehensive approach that integrates transport systems with other dimensions of urban life, such as public space, infrastructure, environmental protection, and social equity. The true strength of these models lies in their capacity to transcend traditional concepts of transportation and offer innovative, holistic solutions that enhance quality of life, reduce pollution, and increase urban resilience to current global challenges.

The key findings emphasize the multidimensional nature of sustainable urban transport development. Technological innovation constitutes one of the core elements of this process: the introduction of electric vehicles, smart traffic management systems, and the integration of public transport with active mobility modes such as walking and cycling play a crucial role in shaping sustainable transport solutions. Equally important is the need for long-term urban planning policies that reduce dependence on private cars, strengthen public transport, and improve pedestrian and cycling infrastructure. Sustainable transport must also be grounded in the principles of inclusivity and social equity. Furthermore, sustainable mobility should be an integral part of climate adaptation strategies, reducing cities' carbon footprints and accelerating the transition to renewable energy sources within the transport sector. While each city possesses unique characteristics and local challenges, concepts such as “smart cities” and the “15-minute city” offer valuable and adaptable frameworks for transport development aligned with the principles of sustainability. Cities like Copenhagen and Paris serve as inspiring examples and strategic models for other urban environments aiming to improve quality of life, enhance environmental resilience, and promote social justice through sustainable transport.

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