

SMART MOBILITY IN SMART CITY – COPENHAGEN AND BARCELONA COMPARISON

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Purpose: The goal of the paper is to analyze the main differences between the smart mobility idea implementation in Copenhagen and Barcelona.

Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and Polish literature and legal acts connecting with researched topic.

Findings: The paper compares the smart mobility solutions implemented in Copenhagen and Barcelona, two cities that have developed comprehensive and innovative transportation systems. While both cities have sustainable, efficient, and convenient transportation systems, they differ in their focus and governance structure. Copenhagen is a leading city in sustainable transportation, with a strong focus on cycling infrastructure and an integrated public transportation system. On the other hand, Barcelona focuses on reducing traffic congestion and improving air quality, with innovative solutions such as a low-emission zone and a smart parking system. Additionally, Copenhagen has a highly centralized governance structure, while Barcelona adopts a more decentralized approach, engaging citizens and stakeholders in transportation decision-making.

Originality/value: Detailed analysis of differences between Copenhagen and Barcelona in the case of smart mobility implementation.

Keywords: Smart City, smart mobility, smart biking, sustainability, cycling.

Category of the paper: research paper.

1. Introduction

Smart mobility plays a crucial role in smart cities by providing efficient and sustainable transportation solutions that meet the needs of residents and visitors while reducing congestion, improving air quality, and enhancing quality of life. Smart mobility solutions are designed to optimize the use of transportation infrastructure and resources through the use of technology and data.

One of the primary goals of smart mobility in a smart city is to promote sustainable transportation modes such as cycling, walking, and public transportation, and to reduce dependence on single-occupancy vehicles. This can be achieved through the development of cycling infrastructure, bike-sharing schemes, and integrated public transportation systems that make it easy for people to get around the city.

The goal of the paper is to analyze the main differences between the smart mobility idea implementation in Copenhagen and Barcelona.

2. Smart Mobility in Smart City

Smart mobility involves the use of technology to improve the efficiency of transportation systems. For example, smart traffic management systems can use real-time data to monitor traffic flow and adjust traffic lights to optimize traffic flow and reduce congestion (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023, Orzeł, Wolniak, 2021, 2022; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021). Similarly, smart parking systems can use sensors to detect available parking spaces and direct drivers to the nearest available spot, reducing the time spent looking for parking and minimizing congestion (Wolniak, Sułkowski, 2015, 2016; Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022; Wolniak, 2013, 2016; Hys, Wolniak, 2018).

In addition to improving transportation efficiency, smart mobility solutions can also enhance safety and accessibility (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021). For example, intelligent transportation systems can provide real-time information to pedestrians and cyclists about potential hazards or delays, while also providing real-time information to public transportation users about delays or service disruptions (Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023).

3. Smart Mobility solutions in Copenhagen

Copenhagen is one of the leading cities in the world when it comes to smart mobility solutions. The city has a long-standing commitment to sustainable transportation and has implemented a range of innovative initiatives to promote cycling, walking, and public transportation while reducing car dependency and improving air quality (Bjørner, 2021).

One of the key smart mobility solutions used in Copenhagen is the development of cycling infrastructure. The city has invested heavily in building a network of dedicated bike lanes and cycle paths, making it easy and safe for cyclists to navigate the city. The city's bike-sharing scheme, which allows residents and visitors to rent bikes for a small fee, has also been hugely successful and has contributed to the growth of cycling as a primary mode of transportation in the city (Cenre, 2017).

Another smart mobility solution used in Copenhagen is the integration of public transportation systems. The city has a comprehensive network of buses, trains, and metro lines that are integrated into a single ticketing system, making it easy and convenient for residents and visitors to use public transportation. The city has also introduced real-time information displays at bus and train stops, allowing passengers to see exactly when the next bus or train is due (Eltved et al., 2021).

Copenhagen has also implemented a range of smart traffic management solutions to reduce congestion and improve traffic flow. The city's intelligent traffic management system uses real-time data to monitor traffic flow and adjust traffic lights to optimize traffic flow and reduce congestion. The city has also introduced a smart parking system that uses sensors to detect available parking spaces and directs drivers to the nearest available spot, reducing the time spent looking for parking and minimizing congestion (Doost, Rezaie, 2020).

In addition to these initiatives, Copenhagen has also introduced a range of smart mobility solutions to enhance safety and accessibility. The city has introduced pedestrian and cyclist detection systems at key intersections, alerting drivers to the presence of pedestrians and cyclists and reducing the risk of accidents. The city has also introduced a range of accessibility initiatives, including low-floor buses and tactile paving for visually impaired pedestrians (Bager, Mundaca, 2021).

Copenhagen's smart mobility solutions are focused on promoting sustainable transportation modes, improving transportation efficiency, and enhancing safety and accessibility. The city's commitment to sustainable transportation has not only improved the quality of life for residents, but it has also positioned Copenhagen as a leader in the global effort to reduce greenhouse gas emissions and combat climate change (Copenhages, 2020).

In the table 1 there is a description of realization of main factors of smart mobility concept realization in Copenhagen. The city's investment in cycling infrastructure has created a dedicated network of bike lanes and cycle paths, which has contributed to the growth of cycling as a primary mode of transportation in the city. The integration of public transportation systems has made it easy and convenient for residents and visitors to use public transportation,

and the use of real-time information displays has improved the user experience. The city's smart traffic management system and smart parking system have helped to reduce congestion and improve traffic flow, while the introduction of pedestrian and cyclist detection systems has enhanced safety and accessibility for vulnerable road users (Mortensen et al., 2020).

Table 1.

Main factors of smart mobility in Copenhagen

Factor	Realization
Cycling Infrastructure	Copenhagen has invested heavily in building a network of dedicated bike lanes and cycle paths, making it easy and safe for cyclists to navigate the city. The city's bike-sharing scheme, which allows residents and visitors to rent bikes for a small fee, has also been hugely successful and has contributed to the growth of cycling as a primary mode of transportation in the city.
Public Transportation Integration	Copenhagen has a comprehensive network of buses, trains, and metro lines that are integrated into a single ticketing system, making it easy and convenient for residents and visitors to use public transportation. The city has also introduced real-time information displays at bus and train stops, allowing passengers to see exactly when the next bus or train is due.
Smart Traffic Management	Copenhagen's intelligent traffic management system uses real-time data to monitor traffic flow and adjust traffic lights to optimize traffic flow and reduce congestion. The city has also introduced a smart parking system that uses sensors to detect available parking spaces and directs drivers to the nearest available spot, reducing the time spent looking for parking and minimizing congestion.
Safety and Accessibility	Copenhagen has introduced pedestrian and cyclist detection systems at key intersections, alerting drivers to the presence of pedestrians and cyclists and reducing the risk of accidents. The city has also introduced a range of accessibility initiatives, including low-floor buses and tactile paving for visually impaired pedestrians.
Sustainable Transportation Promotion	Copenhagen's smart mobility solutions are focused on promoting sustainable transportation modes, including cycling, walking, and public transportation. The city has also introduced incentives for sustainable transportation, such as a congestion charge for drivers entering the city center, which has helped to reduce car dependency and improve air quality.

Source: Authors own work on the basis of: (Bjørner, 2021; Cenre; 2017; Eltved et al., 2021; Doost, Rezaie, 2020; Bager et al., 2021; Copenhagen, 2020; Mortensen et al., 2020).

In the table 2 there is an analysis of main advantages and problems in implementation of smart mobility solutions in Copenhagen.

Table 2.

Comparison of advantages and problems of implementing smart mobility in Kopenhagen

Advantages	Problems
Promotes sustainable transportation modes such as cycling, walking, and public transportation	Limited space for expanding cycling infrastructure and public transportation systems
Reduces car dependency and improves air quality	Resistance from some residents and businesses to changes in transportation infrastructure and systems
Increases transportation efficiency and reduces congestion	High cost of implementing smart mobility solutions
Enhances safety and accessibility for pedestrians and cyclists	Need for ongoing maintenance and upgrades to smart mobility systems
Positions Copenhagen as a leader in sustainable transportation and climate action	Limited resources and funding for implementing smart mobility solutions

Source: Authors own work on the basis of: (Bjørner, 2021; Cenre; 2017; Eltved et al., 2021; Doost, Rezaie, 2020; Bager et al., 2021; Copenhagen, 2020; Mortensen et al., 2020).

4. Smart Mobility solutions in Barcelona

Barcelona is a city that has been at the forefront of innovation in smart mobility solutions. The city has implemented a range of initiatives aimed at promoting sustainable transportation and reducing congestion, including bike-sharing schemes, electric vehicles, and a network of smart parking systems (Eicher, 2020).

Barcelona has implemented a bike-sharing scheme, known as Bicing, which allows residents and visitors to rent bikes for a small fee. The scheme has been highly successful and has contributed to the growth of cycling as a primary mode of transportation in the city. Barcelona has also implemented a range of initiatives aimed at promoting cycling, including the creation of dedicated bike lanes and the introduction of bike-sharing schemes for tourists (Rueda Arsanaz, Grimaldi, 2017; Channock et al., 2021).

The analyzed city has invested heavily in electric vehicles, with a goal to make the city's entire fleet of buses and taxis electric by 2025. The city has also introduced a range of incentives for electric vehicle owners, including free parking and charging stations located throughout the city. Barcelona has introduced a network of smart parking systems that use sensors to detect available parking spaces and direct drivers to the nearest available spot. The system has helped to reduce the time spent looking for parking, minimizing congestion and reducing emissions (Eskhita et al., 2021, Smith, Martin, 2021).

Barcelona has a comprehensive network of public transportation, including buses, metro lines, and trams. The city has implemented a smart ticketing system that allows passengers to use a single ticket for all modes of transportation, making it easy and convenient to use public transportation. Barcelona has also introduced real-time information displays at bus and metro stops, allowing passengers to see exactly when the next bus or train is due (Di Martino et al., 2020).

Barcelona's intelligent traffic management system uses real-time data to monitor traffic flow and adjust traffic lights to optimize traffic flow and reduce congestion. The city has also implemented a range of measures aimed at reducing the number of cars on the road, including a congestion charge for drivers entering the city center. Analyzed Spanish city has implemented a range of shared mobility solutions, including car-sharing schemes and ride-sharing services. The city has also introduced a range of initiatives aimed at promoting shared mobility, including the creation of car-free zones and the promotion of carpooling (Bibri, Krogstie, 2020; Mann et al., 2020).

Barcelona has implemented a range of data collection and analysis tools to monitor transportation patterns and improve the efficiency of its transportation systems. The city has introduced a traffic data platform, which collects data from traffic sensors and provides real-time traffic updates to drivers. Barcelona has also introduced a range of initiatives aimed at reducing emissions and improving air quality, including the promotion of electric vehicles and the creation of low-emission zones (Noory et al., 2020).

On the basis of the analysis it can be stated that Barcelona's smart mobility solutions are focused on promoting sustainable transportation modes, including cycling, public transportation, electric vehicles, and shared mobility. The city has invested heavily in smart parking systems and intelligent traffic management to reduce congestion and emissions. Barcelona's data collection and analysis tools have helped to inform future investments in transportation infrastructure, ensuring that the city remains at the forefront of innovation in smart mobility solutions (Mancho, 2020; Vasilenko, Mokhailova, 2019).

In the table 2 there is a description of realization of main factors of smart mobility concept realization in Barcelona. Barcelona's smart mobility solutions are focused on promoting sustainable transportation modes, reducing congestion, and improving air quality. The city has invested heavily in smart parking systems, intelligent traffic management, and data collection and analysis to improve the efficiency of its transportation systems. Barcelona has also implemented a range of pedestrian-friendly initiatives and green spaces to promote sustainable transportation options and improve air quality. The city's smart city initiatives have helped to integrate transportation systems with other city services, creating a more efficient and sustainable city (March, Ribera-Fumaz, 2018, Smart Mobility, 2018).

Table 3.

Main factors of smart mobility in Barcelona

Factor	Realization
Bike-Sharing Schemes	Barcelona has implemented a successful bike-sharing scheme, known as Bicing, which allows residents and visitors to rent bikes for a small fee. The city has also created dedicated bike lanes and introduced bike-sharing schemes for tourists.
Electric Vehicles	Barcelona has invested heavily in electric vehicles, with a goal to make the city's entire fleet of buses and taxis electric by 2025. The city has also introduced a range of incentives for electric vehicle owners, including free parking and charging stations located throughout the city.
Smart Parking Systems	Barcelona has introduced a network of smart parking systems that use sensors to detect available parking spaces and direct drivers to the nearest available spot. The system has helped to reduce the time spent looking for parking, minimizing congestion and reducing emissions.
Integrated Public Transportation	Barcelona has a comprehensive network of public transportation, including buses, metro lines, and trams. The city has implemented a smart ticketing system that allows passengers to use a single ticket for all modes of transportation, making it easy and convenient to use public transportation. Barcelona has also introduced real-time information displays at bus and metro stops, allowing passengers to see exactly when the next bus or train is due.
Smart Traffic Management	Barcelona's intelligent traffic management system uses real-time data to monitor traffic flow and adjust traffic lights to optimize traffic flow and reduce congestion. The city has also implemented a range of measures aimed at reducing the number of cars on the road, including a congestion charge for drivers entering the city center.
Shared Mobility	Barcelona has implemented a range of shared mobility solutions, including car-sharing schemes and ride-sharing services. The city has also introduced a range of initiatives aimed at promoting shared mobility, including the creation of car-free zones and the promotion of carpooling.

Cont. table 3.

Data Collection and Analysis	Barcelona has implemented a range of data collection and analysis tools to monitor transportation patterns and improve the efficiency of its transportation systems. The city has introduced a traffic data platform, which collects data from traffic sensors and provides real-time traffic updates to drivers. Barcelona has also introduced a range of initiatives aimed at reducing emissions and improving air quality, including the promotion of electric vehicles and the creation of low-emission zones.
Pedestrian-Friendly Design	Barcelona has introduced a range of pedestrian-friendly initiatives, including the creation of pedestrian zones and the redesign of streets to prioritize walking and cycling over cars. The city has also implemented a "superblock" system, which creates a network of streets closed to cars, allowing for safe and sustainable transportation options.
Green Spaces	Barcelona has implemented a range of green spaces and park systems, including the creation of large pedestrian-friendly parks and green spaces throughout the city. These initiatives help to promote sustainable transportation options and improve air quality.
Smart City Initiatives	Barcelona has implemented a range of smart city initiatives, including the integration of transportation systems with other city services, such as waste management and public safety. The city has also introduced a range of innovative technology solutions, including smart traffic lights and autonomous vehicles

Source: Authors own work on the basis of: (Eicher, 2020; Rueda Arsanaz, Grimaldi, 2017; Channock et al., 2021; Eskhita et al., 2021; Smith, Martin, 2021; Di Martino et al., 2020; Bibri, Krogstie, 2020; Mann et al., 2020; Noory et al., 2020; Mancho, 2020; Vasilenko, Mokhailova, 2019; March, Ribera-Fumaz, 2018, Smart Mobility, 2018).

In the table 4 there is an analysis of main advantages and problems in implementation of smart mobility solutions in Barcelona.

Table 4.

Comparison of advantages and problems of implementing smart mobility in Barcelona

Advantages	Problems
Reduces traffic congestion and emissions	High implementation costs
Improves air quality	Requires significant infrastructure upgrades
Enhances the quality of life for residents	Limited public acceptance
Promotes sustainable transportation options	Difficulty in changing established travel patterns
Increases access to transportation for all residents	Balancing the needs of different transportation modes
Creates economic opportunities	Requires significant coordination between different city departments
Improves transportation efficiency	Technical challenges in integrating different transportation systems
Improves public safety	Potential privacy concerns with data collection and analysis

Source: Authors own work on the basis of: (Eicher, 2020; Rueda Arsanaz, Grimaldi, 2017; Channock et al., 2021; Eskhita et al., 2021; Smith, Martin, 2021; Di Martino et al., 2020; Bibri, Krogstie, 2020; Mann et al., 2020; Noory et al., 2020; Mancho, 2020; Vasilenko, Mokhailova, 2019; March, Ribera-Fumaz, 2018, Smart Mobility, 2018).

5. Copenhagen and Barcelona comparison

Copenhagen and Barcelona are two cities that have implemented innovative smart mobility solutions to improve transportation in urban areas. Both cities have developed a comprehensive transportation system that is sustainable, efficient, and convenient. However, there are some differences in the smart mobility solutions used in these cities.

Copenhagen is a leading city in sustainable transportation, and it has invested heavily in cycling infrastructure. The city has developed a network of cycling lanes, bike-sharing schemes, and bicycle parking facilities. This has made cycling a popular and safe mode of transportation for the city's residents. In addition, Copenhagen has implemented an integrated public transportation system, which includes buses, metro, and trains. The city's transportation system is also designed to be accessible to all residents, including those with disabilities (Bjørner, 2021; Cenre; 2017; Eltved et al., 2021; Doost, Rezaie, 2020).

Barcelona, on the other hand, has developed a smart mobility system that is focused on reducing traffic congestion and improving air quality. The city has implemented a low-emission zone in the city center, which restricts the entry of high-polluting vehicles. Barcelona has also developed an innovative smart parking system, which uses sensors to detect available parking spaces in real-time. This has reduced the time drivers spend searching for parking and has also reduced traffic congestion (Bibri, Krogstie, 2020; Mann et al., 2020; Noory et al., 2020).

Another difference between the two cities is their approach to smart mobility governance. Copenhagen has a highly centralized governance structure, with a strong role for the city government in transportation planning and management (Bjørner, 2021; Cenre; 2017; Eltved et al., 2021; Doost, Rezaie, 2020). In contrast, Barcelona has adopted a more decentralized approach, with a focus on engaging citizens and stakeholders in transportation decision-making.

Cities analyzed in the paper have both implemented smart mobility solutions that have improved transportation in urban areas. However, their approaches differ in terms of the focus of their solutions and the governance structures used to implement them. Copenhagen has focused on sustainable transportation, while Barcelona has focused on reducing congestion and improving air quality. Additionally, Copenhagen has a highly centralized governance structure, while Barcelona has a more decentralized approach.

In the table 5 there is a comparison of smart mobility implementation in Copenhagen and Barcelona. The more extensive comparison was prepared in the table 6.

Table 5.
Comparison of Copenhagen and Barcelona smart mobility solutions

Factor	Copenhagen	Barcelona
Focus of smart mobility solutions	Sustainable transportation, cycling infrastructure, integrated public transportation system	Reducing traffic congestion, improving air quality, smart parking system
Cycling infrastructure	Network of cycling lanes, bike-sharing schemes, and bicycle parking facilities	Developing cycling infrastructure as a priority
Public transportation system	Integrated system including buses, metro, and trains	Developing metro system as a priority
Governance structure	Highly centralized with strong role for city government	Decentralized with focus on engaging citizens and stakeholders
Smart parking system	Not a major focus	Innovative smart parking system using sensors to detect available parking spaces in real-time
Low-emission zone	Not implemented	Implemented in the city center

Source: Authors own work on the basis of: (Eicher, 2020; Rueda Arsanaz, Grimaldi, 2017; Channock et al., 2021; Eskhita et al., 2021; Smith, Martin, 2021; Di Martino et al., 2020; Bibri, Krogstie, 2020; Mann et al., 2020; Noory et al., 2020; Mancho, 2020; Vasilenko, Mokhailova, 2019; March, Ribera-Fumaz, 2018, Smart Mobility, 2018).

Table 6.
Extensive analysis of differences between Copenhagen and Barcelona in smart mobility solutions implementation

Factor	Copenhagen	Barcelona
Overview of Smart Mobility Solutions	Copenhagen is a leading city in sustainable transportation and has invested heavily in cycling infrastructure. The city has developed a network of cycling lanes, bike-sharing schemes, and bicycle parking facilities. It has also implemented an integrated public transportation system, which includes buses, metro, and trains.	Barcelona has developed a smart mobility system that focuses on reducing traffic congestion and improving air quality. The city has implemented a low-emission zone in the city center, which restricts the entry of high-polluting vehicles. Barcelona has also developed an innovative smart parking system, which uses sensors to detect available parking spaces in real-time.
Cycling infrastructure	Copenhagen has developed a comprehensive cycling infrastructure that spans over 400 kilometers of cycle lanes, with a further 100 kilometers planned. The city also has a bike-sharing scheme called Bycyklen, with 1,860 bikes available for rental across 100 stations. Additionally, there are bicycle parking facilities across the city, including indoor parking facilities at train and metro stations.	Barcelona is developing its cycling infrastructure and has implemented a bike-sharing scheme called Bicing, with over 7,000 bicycles available for rental across 420 stations. The city is planning to add 200 kilometers of cycle lanes by 2024, with the aim of reducing the use of cars for short trips and improving air quality.
Public transportation system	Copenhagen's public transportation system is integrated, making it easy for residents and visitors to travel within the city. It includes buses, metro, and trains, and is operated by a single transport authority, Movia. The city has also implemented a smart ticketing system, which allows passengers to use a single ticket across all modes of transportation. Additionally, Copenhagen has a plan to introduce a driverless metro by 2025.	Barcelona's public transportation system includes buses, metro, and trains, and is operated by two transport authorities, TMB and FGC. The city has a comprehensive ticketing system that allows passengers to use a single ticket across all modes of transportation. Barcelona is also developing its metro system, with plans to add 30 kilometers of new lines and 50 new stations by 2026.

Cont. table 6.

Governance structure	Copenhagen has a highly centralized governance structure, with a strong role for the city government in transportation planning and management. The city government sets policies and strategies for transportation, and is responsible for implementing and managing the transportation system.	Barcelona has a decentralized governance structure, with a focus on engaging citizens and stakeholders in transportation decision-making. The city government works closely with local communities and neighborhood associations to develop transportation policies and plans. There is also a strong emphasis on public participation and consultation in transportation projects.
Smart parking system	Copenhagen has not implemented a smart parking system on a city-wide basis, but it has introduced parking guidance systems in some areas. These systems use sensors to detect available parking spaces and display the information on electronic signs, making it easier for drivers to find parking.	Barcelona has developed an innovative smart parking system, which uses sensors to detect available parking spaces in real-time. The system is integrated with a mobile app, which allows drivers to find available parking spaces and pay for parking. This has reduced the time drivers spend searchi

Source: Authors own work on the basis of: (Eicher, 2020; Rueda Arsanaz, Grimaldi, 2017; Channock et al., 2021; Eskhita et al., 2021; Smith, Martin, 2021; Di Martino et al., 2020; Bibri, Krogstie, 2020; Mann et al., 2020; Noory et al., 2020; Mancho, 2020; Vasilenko, Mokhailova, 2019; March, Ribera-Fumaz, 2018, Smart Mobility, 2018).

6. Conclusion

The paper analyzes the smart mobility solutions implemented in Copenhagen and Barcelona to improve urban transportation. Both cities have developed a comprehensive transportation system that is sustainable, efficient, and convenient. However, there are differences in the smart mobility solutions used in these cities. Copenhagen has invested heavily in cycling infrastructure, making cycling a popular and safe mode of transportation. The city has also implemented an integrated public transportation system that is accessible to all residents, including those with disabilities.

On the other hand, Barcelona has focused on reducing traffic congestion and improving air quality by implementing a low-emission zone in the city center and an innovative smart parking system that uses sensors to detect available parking spaces in real-time. Additionally, Copenhagen has a highly centralized governance structure, while Barcelona has a decentralized approach. The paper includes a comparison table and an extensive analysis of the differences between the two cities' smart mobility solutions implementation.

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