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The Influence of Sustainable Urban Mobility on the Urban Morphology of Copenhagen City

Lobna Ahmed Galal

Lecturer Assistant; Faculty of engineering, October University for Modern Sciences and Arts
E-mail: lahmed@msa.edu.eg

Abstract

Transportation has a large impact on greenhouse gas emissions, which have been linked in various studies to adverse environmental effects and climate change. To aid in the development of sustainable urban mobility planning, various strategies have been created. While decreasing dependency on private vehicles, these strategies promote access to services by walking, cycling, and public transportation. This study investigates the paradigm change from the "Finger plan" in 1947 to the pedestrianization of "Stroget" in 1962 to the cycling policy of 2002–2012. It aims to examine the morphological evolution of the city in terms of prioritizing the sustainable modes of urban mobility. Investigating the development of Copenhagen's urban morphology on the two scales: macro and micro scale. The macro scale investigation comprises regional planning, city growth, street networks, cycling tracks, bridges, super highway cycling system, and exploring the compact Copenhagen's city centre. Moreover, the micro scale investigation comprises Copenhagen's bicycle infrastructure; Copenhagen-style bicycle lanes, street design, and sidewalks.

Keywords: Urban mobility, walkability, bicycle friendly, morphology, climate change.

1. Introduction

Many studies have been conducted in an effort to define urban morphology and explain how various urban factors may affect it. Numerous studies have looked at the connection between urban form and mobility, especially in developed countries. The goal was to promote sustainable urban mobility in cities for its advantages to the environment, the economy, the social sector, and public health [1].

On the other hand, urban morphology is the study of the city as "human habitat." The ethnographer Lévi-Strauss also referred to the city as "the most complex of human inventions, at the confluence of nature and artefact," in his description of it. Urban morphologists also examine a city's development, from its foundation to its later modifications, and they identify and categorize its various components [1].

Additionally, it was stated that urban morphology is a method for analyzing and creating "urban form," which deals with the physical and spatial elements of the urban structure, such as plots, blocks, roadways, buildings, and open spaces. These components are a part of the history and development process of the city [2].

Urban morphology was also characterized as an analytical method for comprehending how a place has changed through time and how that understanding might focus attention on a city's evolutionary tendencies [3]. Cities are never still; they resist efforts to make sense of them", and it is needed to consider and respect their rhythms and recognize that the "*life of city form must be loosely somewhere between total control and total freedom of actions. Between conservation and process, process must have the final word. In the end, urban truth is in the flow*" [4].

1.1. Urban morphology and sustainable urban mobility

Numerous metropolitan areas in Europe have supported urban growth along train lines as a strategy and a goal for achieving both sustainable urban development and the creation of coherent territories between cities [5].

As a result, numerous studies have examined the relationship between urban form and transportation patterns or evaluated the impact of urban planning on sustainability and transportation. While others have studied the changes in commuting patterns, some of them have noted how urban form and location patterns have developed over time. This has made it easier and more convenient to use time-series data across several nations. However, few studies have integrated these two viewpoints to examine the stability and consistency of urban design and location-based transportation factors during processes of regional development or other substantial shifting situations [6].

1.2. Sustainable urban mobility

It is a new paradigm that focuses on urban travel (time, duration), urban form (compact), and the promotion of sustainable modes of transportation (walking, cycling, and

taking public transportation) in replacement of private cars. It aims to reduce trip lengths and time by creating compact cities with accessible urban centers within 10-15 minutes on foot or by bicycle, facilities of mixed-use within a reasonable time, and comfort by foot, bike, or public transportation. It also promotes sustainable modes of transportation for getting to work, activities, and facilities in cities [7].

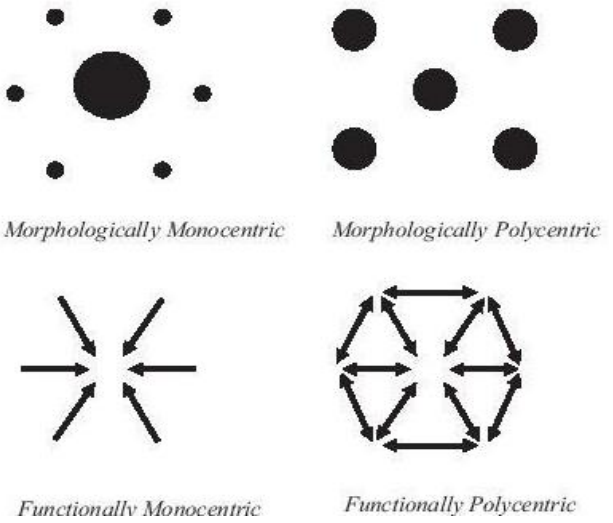

Figure.1 Morphological poly-centricity and functional poly-centricity [8].

A mono-centric urban form is one in which the majority of jobs and commercial facilities are located in the city's core while the majority of households are located on the outskirts. Most of these forms result in radial trips, where the concentration of vehicles near the center occasionally causes severe traffic congestion. Additionally, it promotes and facilitates the growth of extensively sustained radial public transportation networks [7].

A multi-cantered or sometimes called poly-centric form, on the other hand, creates more dispersed and scattered, lateral and cross-town patterns of travel, fostering flexible modes of mobility like private cars. By utilizing the sub-centers to connect quality and synchronized train services, polycentric urban design may readily provide effective public transportation services [7].

Copenhagen emphasized the accessibility of activities and services in the center by sustainable modes of mobility such as walking, cycling, and public transportation rather than adopting the idea of decongesting the city core. The complexity of a city and its potential for future traffic conditions increase with its size, as larger cities have higher densities and, consequently, higher traffic densities (vehicles traveling roads per square kilometer). This relationship also exists for average trip lengths, which increase with city size, contributing to increased traffic congestion and, ultimately, environmental pollution [8].

2. Area of study: Copenhagen; 'The sustainable city; the city of cyclists'

Copenhagen City was selected as the study's case since it helps identify the goal of the study, which is to examine sustainable urban mobility as a paradigm shift away from traffic and automobiles and toward sustainable modes of transportation such as walking, cycling, and public transportation. The term "green mobility," which prioritizes the use of bicycles, walking, and public transportation as modes of transportation in cities, emerged in city planning and had a significant impact on the urban morphology of the city, in both scales, the macro and the micro scale. The concept of the "sustainable city" was actively promoted in Copenhagen.

2.1. Urban form, transport and accessibility in Copenhagen

The development of the city is oriented to mixed-use, inner-urban neighborhoods along designated transit corridors, to accommodate transportation policies. Copenhagen's transportation plans prioritized cutting back on carbon emissions, easing traffic and the use of private cars, boosting multi-modal integration, and promoting cycling, walking, and public transportation. These regulations help Copenhagen achieve its goals of being the "best bicycle city." From 2000 to 2010, the transportation sector's carbon emissions were effectively reduced.

2.2. The Five-Finger plan" in-1947 and its influence on the public transportation system in Copenhagen.

The finger plan introduced and suggested the city's growth and development in the form of fingers to the "palm" of the existing built-up areas rather than allowing it to take the form of concentric layers. Additionally, the wide space between the fingers should have been set aside for recreational uses.

The finger plan attempted to focus new urban growth along suburban train lines that were emerging from Copenhagen [9].

Figure 2. Copenhagen's morphological evolution; on the left, the historic Copenhagen, a coastal community with natural protection; in the center, the city in 1817; on the right, the finger plan; and the city's growth along the main rail corridors in the metropolitan area.

The 1947 first 'Finger plan' recommended that urban development of the Copenhagen metropolitan area proceed along five suburban railroads to support easy access between suburban areas and business locations in the city center, while the areas between should be kept free of buildings to form green wedges, thereby supplying the urban population with recreational areas.

Its objective was to promote mobility for Copenhagen residents without access to cars by improving public transportation and reducing the need for cars in urban areas by maintaining as many jobs and activities as possible in the urban core or other areas with high public transportation accessibility [10].

The finger plan has recently been expanded southward. Such development emphasizes the importance of sustainable development, urban planning, and public transportation. Then, it moved southward as Copenhagen's linear new town, which was constructed over 30 years (starting in the late 1990s) in accordance with the finger plan concept and developed around stations and a mini-metro line [11].

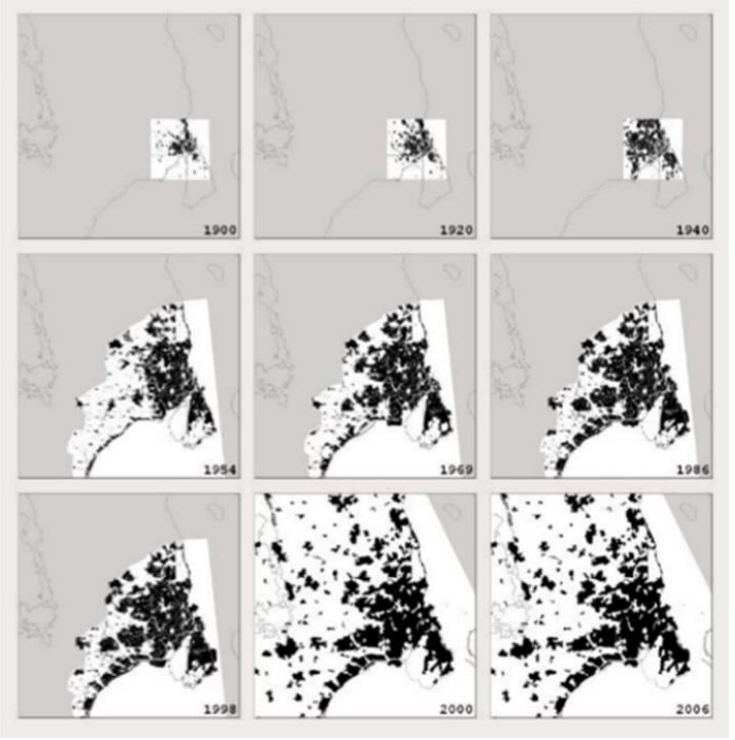

Figure 3. The changing urban morphology of Copenhagen from 1900-2006 [10].

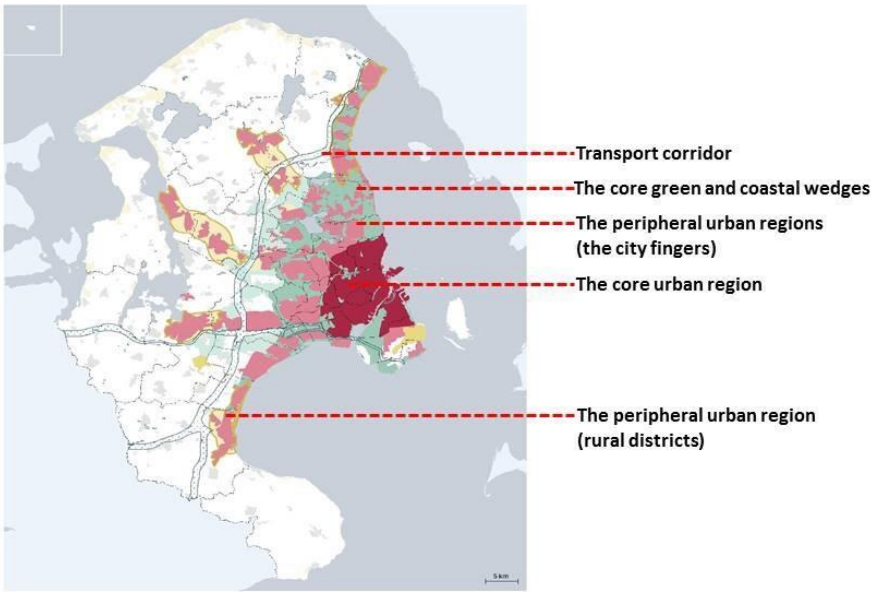

Figure 4. The morphology of Copenhagen's city following the Finger plan development [12].

Figure 5. Satellite image of Copenhagen with the location of the Ørestad [13].

2.3. The shift from traffic to pedestrianization, and its influence on street design, and activities

The paradigm shift in transportation was poised to make cycling and walking more prevalent than vehicles. Shifting away from the vehicle invasion of the 1950s and early 1960s owing to its detrimental effects, including traffic congestion, pollution, and accidents. After that, the environmental movement and the oil crisis both supported and prioritized sustainable urban mobility in cities, which includes frequently walking, cycling, and public transportation.

In parallel with reducing the use of private automobiles, which led to a dramatic alteration in the city's urban morphology on both the macro and micro dimensions, many places that were predominately car-dependent in the 1960s are now car-free zones, including Stroget, Nyhavn, and Langelinie.

The first pedestrian street in Copenhagen was the commercial district known as "Strøget" in 1962. As a result, 35% more people walked in the first year. The narrow medieval streets that were once used by buses and cars have been transformed into a comfortable pedestrian areas. This change affected a large number of streets and locations, including "stergade, Vimmelskaftet, Ama-gertorv, Nygade, Nytorv, and Fredriksberggade" [9-14-15].

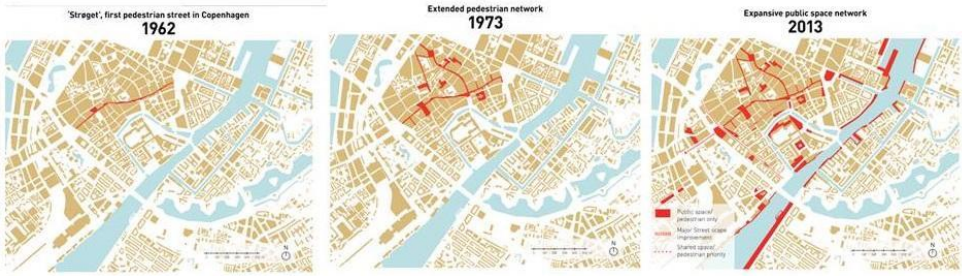

Figure 6. The morphological evolution of Copenhagen in terms of pedestrianization of "Stroget," the first pedestrian street in 1962, the extended pedestrian network in 1973, and the expansive public space network in 2013 [16].

The two most significant squares in Copenhagen, Stroget and the King's New Market comprised the 13,700 square kilometer pedestrian area in 1962. By 1973, the city's pedestrian area had grown to 50,150 square meters, consisting of the streets "Fiolstraede" and "Kbmagergade" as well as other significant shopping districts. Then, by 1996, the network of a 15-km/h zone with no through traffic and priority for cyclists and walkers had been extended to about 94,000 square meters, including the "Alley" or the "Parallel Stroget" [9].

Contrarily, it was noted that between 1962 and 2005, the size of the space designated for people in Copenhagen increased seven times, or, in other words, the area allocated for pedestrians and city life increased by a factor of seven, which led to an increase in the number of people walking in the city. Additionally, the city improved in terms of comfort and social space [14], as seen in Figure. 7.

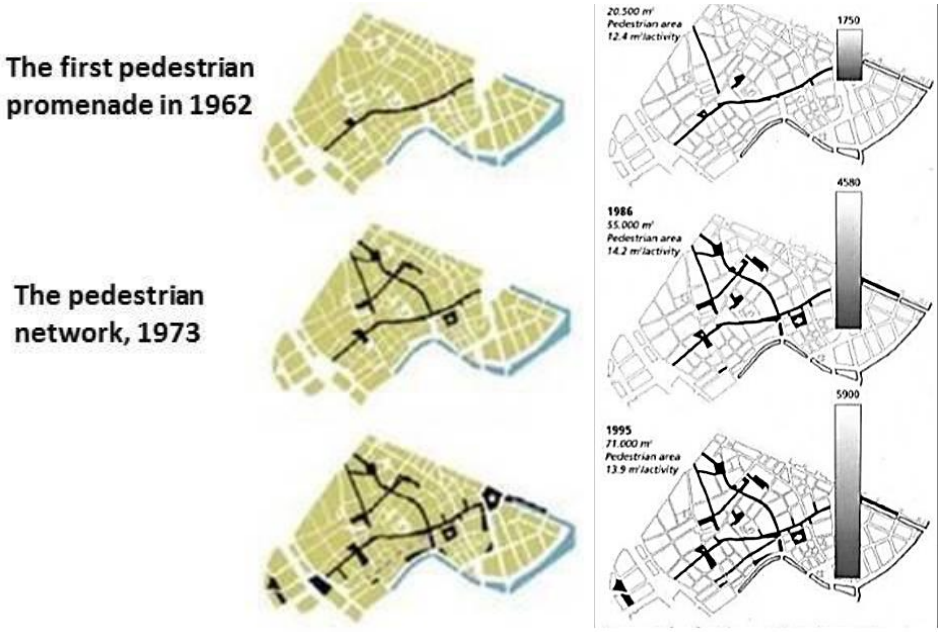

Figure 7. The development of pedestrian areas in the city from 1962, and in the right; the average number of people engaged in stationary activities in the city center (from noon to 4 pm) from 1968, 1986, and 1995 [14-15].

2.4. City compactness:

City compactness and activities that provided good city space for people were influenced by pedestrianization, cycling, and public transportation. It is noted that there is a "magic" of 1-kilometer city center's size (0.39 square mile: a distance of 500 meters-0.3 miles), which supports a suitable and appropriate stroll. As a result, pedestrians may access the majority of services and activities they require in the city with a walk of no more than one kilometer.

Stroget, Copenhagen's largest pedestrian street, is 1 km long and nearly runs from one end of the city center to the other. It is winding and has four squares dividing it, making it an intriguing walk along [14].

With significant mass transit use and cycling mobility, the city is a global leader in cycling mobility. More than half of the metropolitan area's population resides within 1 km and almost a quarter within 500 m of a train station. The built-up area of the Copenhagen region increased dramatically over the 20th century, increasing most quickly from the 1950s to the 1980s. According to the "Finger Plan," urban expansion in Copenhagen's periphery was somewhat focused along rail lines, which encouraged a more energy-efficient rail-oriented urban form [17].

Aside from that, it was highlighted that the city has a robust public transportation infrastructure that includes a suburban railway, a metro system, and bus networks, meaning that the majority of Copenhagen citizens reside within 350 meters (0.2 miles) of public transportation services. The city of Copenhagen, which is renowned for the ease with which its citizens can cycle around the city, benefited from the proximity of public transportation hubs by promoting both walking and cycling as well [18].

2.5. The shift to cycling

In the 1950s and early 1960s, cars were attempting to displace walking and cycling, however, they also contributed to traffic congestion, pollution, and accidents. Afterward, due to the oil crisis and the environmental movement, this trend was reversed. And in Copenhagen's city streets, cycling, walking, and public transportation now take precedence. In addition, trip chaining—the integration of these modes of transportation during journeys—and the use of motor vehicles were also strongly encouraged. Stroget, Nyhavn, and Langelinie are just a few examples of the significant districts of Copenhagen that were once car-dominated and marked by heavy traffic and parking lots but are now car-free zones. Moreover, in the past ten years, there have been several new challenges, and the need to enhance public health and mitigate climate change has never been greater. It has prompted a tremendous effort to protect and support the cycling culture in Copenhagen [19].

The city of Copenhagen released a bicycle policy for the first time in 2002. Its aim was to promote cycling as a feasible and environmentally friendly mode of transportation. The goals of the bicycle policy included increasing the percentage of workers who commute to work by bicycle, enhancing safety and security, and enhancing comfort and speed while bicycling [9].

Copenhagen's bicycle traffic has increased recently, and as of 2011 (one-third of all Copenhageners use the bike for their trips to work or school). Owing to the roughly 300 km network of bicycle lanes in Copenhagen, the bicycle traffic there is regarded as a unique traffic type with its own dedicated road area for motor vehicles and pedestrians. It may be concluded that the bicycle strategy is growing the Copenhagen cycling tradition with tracks along all main roads (not motorways) and a system of environmentally friendly bicycle paths. Increasing traffic and CO2 emissions, which have increased despite a 15% reduction in emissions between 1990 and 2002, were Copenhageners' biggest concern. The city of Copenhagen had plans and policies that addressed issues related to cycling in the city, including the Cycle Priority Plan 2006-2016 and the Copenhagen Bicycle Strategy 2011-2025, which is a continuation of the Cycle Policy 2002-2012 [20].

In approximately the last ten years, the city invested over €134 million in cycling infrastructure and facilities. In the world's most thorough rating of bicycle-friendly cities, the "Copenhagenize" index 2017, Copenhagen came in first place out of 136 cities [21].

Spending on bicycle facilities numerous studies have demonstrated the social, economic, environmental, and health advantages of urban cycling. According to studies

from Denmark, cycling has various significant economic advantages. For every kilometer cycled, society makes a net profit of 23 cents, compared to a net loss of 16 cents for every kilometer driven by a car.

The "green cycle track system" and the "cycle super highway system" were two initiatives in the domain of cycling policy. In order to provide cyclists with the experience of green areas, the natural environment, urban spaces, and calm and direct routes, the green cycle tracks were created to cross the city and create an autonomous network of travel routes. In 2008, the first green cycle track was inaugurated. By 2012, the tracks had been expanded over a distance of 43 km, and 22 routes comprising 110 km of cycle tracks were planned [23].

The aim of the Green Cycle Routes program was to make it possible for people to commute into the city on bicycles while passing by or through parks and other open spaces. There will eventually be twenty-one routes reaching one hundred kilometers in length [9].

2.6. Bicycle and pedestrian bridges

Cities require mobility strategies and solutions as urbanization increases. Infrastructure is crucial for mobility; in Copenhagen, rules have developed over a century and now include creating protected, one-way bike lanes that aren't shared with vehicles, pedestrians, or buses. It entails creating public spaces that are safe and welcoming for everyone, not just drivers, and constructing roadways to reduce the number of vehicles and their speeds in urban areas [25].

Copenhagen's proximity to the water makes it difficult for people and commodities to cross the port, thus in 2006, a bridge was built to allow bicyclists to travel from the harbour to the inner city. According to 2012 research, 70% of commuters who cross the bridge on their way to work chose to cycle along it to travel more quickly. As a result, between 2012 and 2014, the city's bicycle modal share increased significantly, rising from 36% to 45%. North of the city, there is also a bicycle bridge over a highway. then, in December 2014, two new bridges over the canal were inaugurated. In addition to newly built bicycle bridges, the "Cykelslangen," or "bike snake," provided a crucial mobility link across the bay [25].

Figure 8. On the left; is the harbor and on the right is the 'Bryggebroen, The Quay bridge' in Copenhagen [26].

2.7. Cycling routes; bridges, and super highways

Copenhagen cycling strategy: the first cycle tracks were first introduced in the mid-20s, the first bicycle network plan was first presented in 1936, and the first individual cycle policy, or "cycle policy 2002-2012," was first introduced in 2002.

On the other side, there were networks of cycling infrastructure in the 1940s Finger Plan, and by 2011, there was 350 km of lanes in the network.

The "green cycle track system" and the "cycle super highway system" were two initiatives in the domain of cycling policy. In order to provide cyclists with the experience of green areas, the natural environment, urban spaces, and pleasant and direct routes, the green cycle tracks were created to cross the city and create an autonomous network of travel routes. In 2008, the first green cycle track was inaugurated. By 2012, the tracks had been expanded over a distance of 43 km, and 22 routes comprising 110 km of cycle tracks were planned [27].

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2.8. The cycle super highways in Copenhagen

For cyclists who travel more than seven kilometers to work, cycle networks with superhighways were built. These networks enhanced the urban environment and reduced traffic.

Given that it links the city's center with the suburbs and has numerous services and amenities for bicycles, it was created to provide simple, safe, and direct routes for people to travel between their homes and places of employment. While the other 26 routes are scheduled for the following years, the first and second cycle super highways opened in 2012 and 2013, respectively.

Figure 9. On the left; the two cycle super highways in Copenhagen [21].

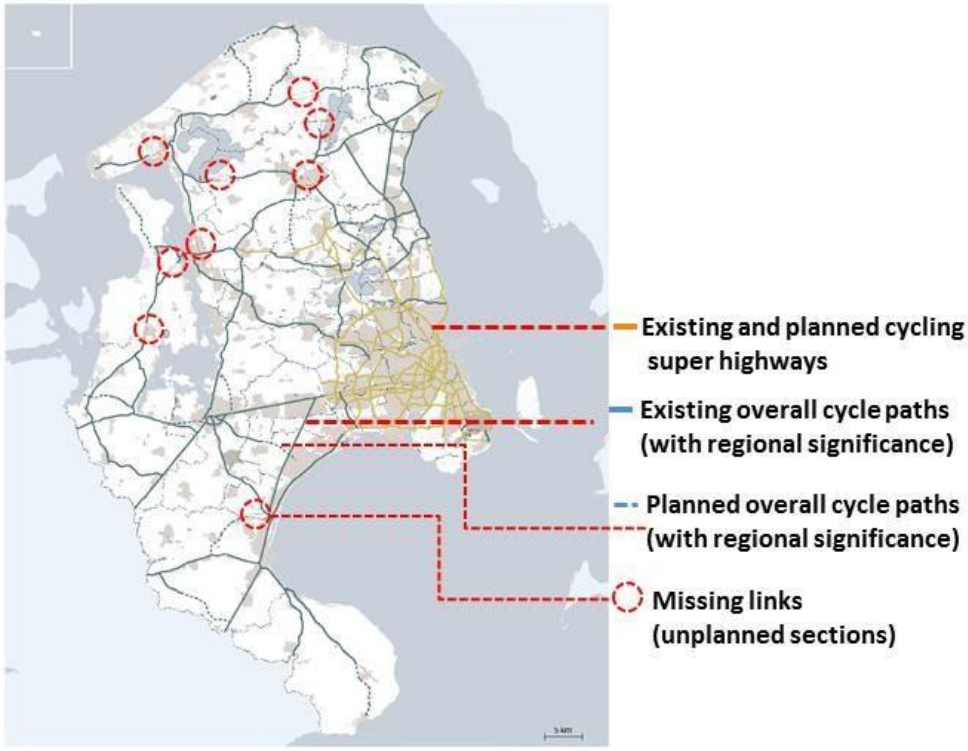

Figure 10. The planned and existing cycling superhighways in Copenhagen [28].

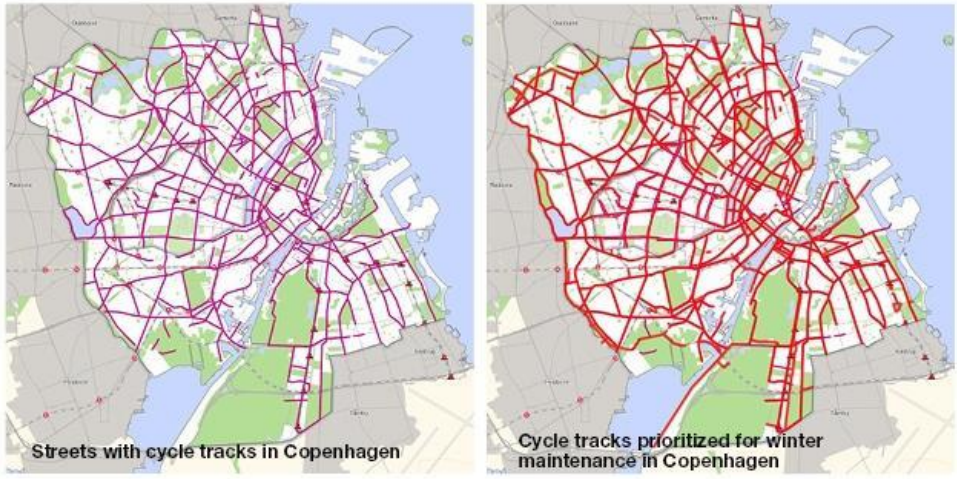

Figure 11. The cycle tracks in Copenhagen [21].

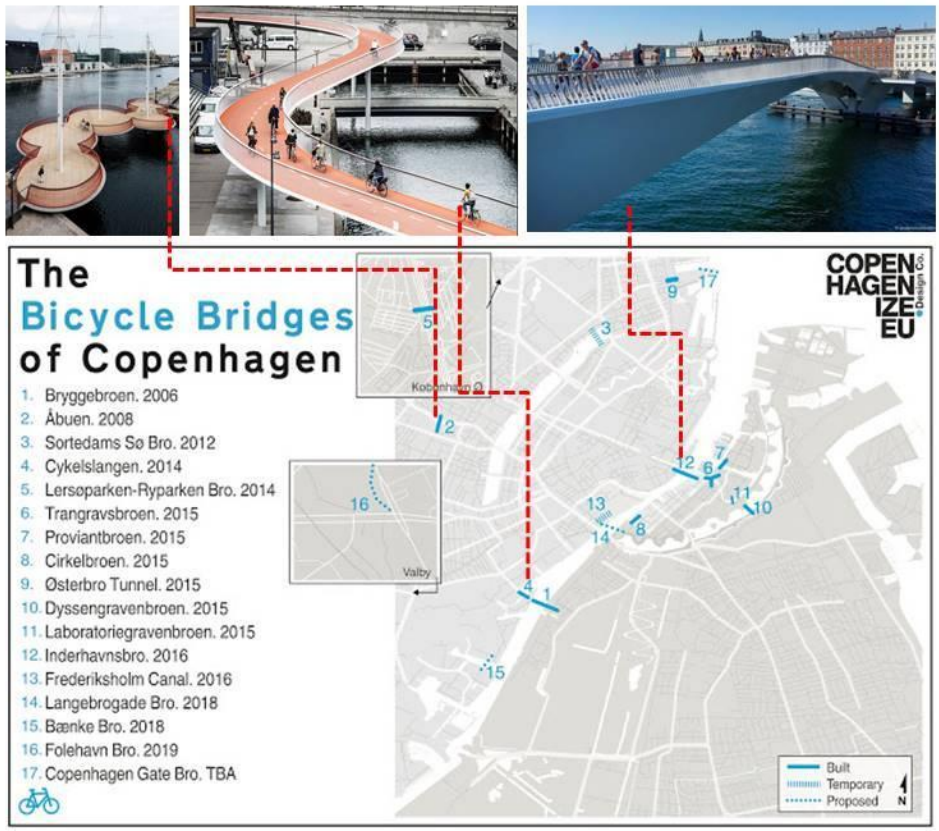

Figure 12. The bicycle bridges in Copenhagen [21].

2.9. The morphological evolution in the micro-scale: the priority given to cycling instead of cars, cycling infrastructure.

Copenhagen is recognized as a "city of cyclists," and due to its extensive cycling infrastructure and the high percentage of regular cyclists, it is frequently cited as an example of a city raising the standard for sustainable mobility. In order to resolve conflicts between cyclists, carriages, and horses, Copenhagen's first cycle lane was constructed in the late 19th century [30].

The paradigm shift from private cars to bicycles and the promotion of cycling, giving priority to walking, bicycling, and public transportation instead of personal vehicles, had a significant impact on the urban morphology of Copenhagen, in two scales; the macro and the micro scale, as follows:

Bicycle tracks that are frequently found going past streets and roads that are segregated from pedestrians and motorized vehicles compensate Copenhagen's bicycle infrastructure.

The bicycle tracks are directed into bicycle lanes that are marked in a different color at crossings that are controlled by traffic lights, and this layout greatly improves the accessibility and safety of cyclists [30].

Streets encourage sustainable modes of mobility, usually cycling and walking, as opposed to driving lanes. The conversion of existing streets into two-way bicycle lanes with bicycle parking, giving priority to pedestrians and bicycles over motor vehicles [30].

Figure 13. The micro-scale of street design gives the priority to cyclists and pedestrians, in the right; the cycling lane that enables cycling to ride in two directions, while cars were restricted to one direction [31].

3. Results and Discussion

This study focused on the effects of urban mobility planning on the morphology of cities. The study looked at the features of the built environment that have an impact on physical activity. Both the macro-scale and the micro-scale of these elements were examined.

The study provided interpretations about urban form and sustainable urban mobility. It elaborated the built environment features that influence walking and cycling, providing a framework for assessing the built environment. It also recommended approaches of design and urban morphology for supporting sustainable urban mobility in cities, as seen in table. 1.

The impacts of planning for cycling and walking on the urban morphology of cities were also underlined. In analyzing the evolution of cities across time, a framework was developed. In order to understand how a location has changed over time and how that

understanding could direct attention on a city's evolutionary tendencies, it is analytically useful to examine the urban morphology of a city.

By analyzing Copenhagen's urban morphology in reference to its mobility system, it was revealed that planning for sustainable urban mobility prioritizes people's needs; creating spaces for people as a priority by enhancing the urban public spaces, dedicated spaces for pedestrians and cyclists, and all of these factors of the built environment promoted the use of walking and cycling (sidewalks, pedestrian crosswalks, walkways, cyclists' lanes and paths, cyclists' bridges). As a result, this has a positive impact on cities' public health, environment, and socioeconomic factors.

A key morphological factor that supports walkable and bicycle-friendly cities is the compactness of the city form and the proximity of daily services and activities that can be obtained within reasonable walking distances of 15 to 20 minutes or less.

Since transportation contributes to a substantial portion of global greenhouse gas emissions, investing in cyclists and pedestrian-friendly cities can help reduce emissions. Regarding the socioeconomic dimensions of mobility promoting access for women, children, and the elderly supports access to services for everyone, and hence achieve social equity.

Access from the point of origin to the point of destination using sustainable modes of transportation is supported through modal integration between walking, cycling, and public transit, which includes areas for parking bicycles close to metro and bus stations.

Table 1. Factors of urban morphology that influence sustainable urban mobility

Macro scale factors					**Micro scale factors**		
Urban form/ compactness	Regional planning	City growth	Street networks	Connectivity: Cycling bridges, tracks, and super highways	Street design	Bicycle infrastructure (Copenhagen-style bicycle lanes)	Pedestrians' infrastructure: Sidewalks Crosswalks

This study identified the built environment features that influence cycling and walking as physical activities. Looking at the local context of Cairo city demonstrated that walking and cycling represent significant challenges for pedestrians. The absence of dedicated paths for cyclists and pedestrians is the cause of this. If there are sidewalks, they are often obstructed by car parking places, street vendors, and hazards like cracks, which makes walking along them unsafe and uncomfortable. Inadequate lighting poles also demonstrate a lack of adequate pedestrian infrastructure by keeping walking unsecure by nigh, particularly for women.

4. Conclusions

This study provided theoretical interpretations and definitions of urban form and sustainable urban mobility. It identified the built environment features that influence walking and cycling and provided approaches and a framework for assessing the built environment and promoting sustainable urban mobility.

This study examined the consequences of sustainable urban mobility in Copenhagen in the immediate aftermath of the car invasion in the early 1950s. Fifty years later, there had been a clear paradigm shift, and there was an urgent need to recognize the vision of Copenhagen as a sustainable city by supporting and promoting sustainable modes of transportation and the modal integration between them. It can be stated that Copenhagen's morphological evolution was influenced by public transportation. According to the "Finger plan" from 1947, the city's growth and development were cantered around rail stations and metro lines. Later, in 1960, "Stroget" became the first area in the city to be pedestrianized, followed by other open spaces. This led to a significant increase in the number of activities in the city center and made the city more compact.

Through generating the framework for assessing the built environment characteristics that affect walkability and the cycling conditions in Cairo, it was revealed that: On their daily trips, pedestrians and cyclists encounter multiple challenges. They experience unsafe and uncomfortable walking and cycling conditions. This is because there aren't enough designated paths for walking and cycling. If they do exist, they are encroached upon by obstacles or activities, such as street vendors, that use their territory for commercial gain. Inadequate elements, such as inefficient lighting and shading, and improper maintenance, all have an impact on the security, comfort, and safety of pedestrians. Therefore, it is recommended that urban street characteristics should be improved to enhance the walking and mobility experiences of pedestrians and cyclists. Significantly positive effects on the environment and public health are directly related to this issue.

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