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Geographic Information System in the Optimization of Tourist Routes in the City of Faro (Algarve, Portugal)

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Abstract: This work aims to map the optimal routes based on time and distance, via e-scooters and walking, to visit 54 historical heritage sites in Faro. Implementing these routes promotes environmental sustainability by reducing CO_2 emissions and encouraging healthier, greener tourism. The route optimization was conducted in ArcGIS, utilizing the Network Analyst extension and vector data obtained from OpenStreetMap. The results showed that there are routes that can be completed in one or more days, depending on visitors' availability, physical capacity, or their chosen method of transportation. The optimal route to visit the 54 historical heritage sites forms a closed circuit spanning 17.35 km. If visits are split into two routes, one covering 31 monuments in the old city and the other 24 monuments in the exterior area of the urban center, the optimal closed-circuit routes measure 6.16 km and 11.31 km, respectively. This study is expected to enhance tourism promoted by the Faro municipality and make it more environmentally friendly.

Keywords: green tourism; GIS; environment; sustainability; urban; e-scooters; walking; historical heritage; optimal routes

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1. Introduction

Tourism is one of the world's most promising and dynamic industries [1]. Its rapid growth has underscored its potential to affect environmental sustainability. It is crucial to recognize its environmental challenges and the urgency of implementing more sustainable practices to minimize its negative impact [2]. Planning and developing tourism sustainably are fundamental to achieving a balance between environmental, economic, and social objectives [3]. To achieve sustainability, stakeholder coordination is vital [4]. Developing synergistic interactions between stakeholders involved in governance processes is essential for effectively sharing tourism benefits [5].

Although tourism contributes significantly to economic development and employment opportunities, it has caused environmental damage due to carbon dioxide (CO_2) emissions associated with excessive energy use [6]. It is a priority for society to understand that tourism represents a significant source of CO_2 emissions and to take adequate measures to mitigate its environmental impact. These measures include promoting more sustainable travel and investing in low-carbon transport.

Reducing CO_2 emissions in mobility has been a constant concern for researchers. Several studies have compared CO_2 emissions in urban areas, considering different modes of transport. These studies highlight the importance of promoting low-carbon transport options and encouraging eco-friendly travel.

For example, Koossalapeerom [7] analyzed the energy consumption and CO_2 emissions of electric and gasoline motorcycles in a city in Thailand. The results demonstrated that electric motorcycles had significantly lower CO_2 emissions than gasoline motorcycles, highlighting the potential of electric alternatives to reduce environmental impacts in urban areas.

Similarly, Kusmayadi [8] investigated the integration of electric scooters into public transport in a tourist city in Bali, emphasizing the effectiveness of these vehicles in reducing CO_2 emissions during trips.

The publication “The New Mobility Times” from the Lufthansa Innovation Hub provides a comprehensive analysis of major urban transportation modes based on their carbon emissions. The study considers not only direct emissions but also the entire lifecycle of each mode of transport, including manufacturing, maintenance, wear, energy consumed during use, and the emitted carbon. According to the report, walking produces the lowest carbon emissions, while gasoline cars are the highest emitters [9].

The Algarve region, located in the south of Portugal with Faro as its administrative and political center, is internationally recognized for its tourist attractions, including its beaches, sun, biodiversity, natural environment, culture, tradition, and hospitality [10]. The region is easily accessible via the Gago Coutinho International Airport in Faro, often serving as the initial holiday destination for international and national tourists. Faro is situated within the Ria Formosa, one of the most important wetlands in southern Portugal, spanning approximately 16,000 hectares and being protected under EU and Portuguese law as a Wetland of International Importance [11].

From the archeological remains, it is possible to affirm that, since the 4th century BC, there were established contacts between the peoples of the Mediterranean and a small peninsula inserted in the Ria Formosa, which is presently named Vila-Adentro. Vila-Adentro is a smooth hill in the old city where the Roman city Ossonoba was founded, Faro [12]. Sousa’s archeological studies [13] showed that at the end of the 2nd century BC, the city was under Roman rule (the republican period). This domain continued during the 1st to 2nd centuries (High Empire) and 3rd to 5th centuries (Late Empire), followed by a troubled period until the 8th century with the Visigoth invasions. Ossonoba was conquered by the Arabs in 713.

In the context of sustainable cities, it is important to make tourist visits more ecological by minimizing CO_2 emissions. Using e-scooters and walking in a medium-sized, flat city like Faro are excellent options to satisfy these requirements. The Faro Municipal Council invested in a greener future, becoming the first city on the Iberian Peninsula to sign the “Shared Mobility for Human Cities” agreement [14]. This instrument that guides sustainable mobility in cities is based on ten principles as follows: (i) Plan cities and mobility together; (ii) Encourage the movement of people rather than the use of cars; (iii) Stimulate the efficient use of the infrastructures; (iv) Actively engage stakeholders in the decision-making process; (v) Ensure physical, digital, and financial access to shared transport services; (vi) Evolve towards zero carbon emissions; (vii) Charge fair rates; (viii) Ensure that shared transport services enable interoperability, competition, and innovation while ensuring privacy, security, and accountability; (ix) Promote the integration and connectivity of transport modes; and (x) Operate autonomous vehicles in dense urban areas only in shared fleets (Shared Mobility Principles, n.d.). In 2019, contracts were signed with private entities to implement scooter sharing in the city [14].

As Faro is a departure and arrival city for international flights, some tourists stay for a short time, so it is important to visit places of interest quickly. According to the National Statistics Institute (INE), the average stay in tourist accommodations is about 1.9 days [15].

The study presented focuses on applying Geographic Information Systems (GIS) to optimize tourist routes in Faro, aiming to minimize environmental impacts and ensure that tourists can visit all places of architectural interest quickly.

As a result of the investigation, cartography was obtained that defines the minimum cost routes, providing tourists with the opportunity to visit and explore, in one or two days, places associated with important events and periods in the city’s history.

The application of GIS in creating tourist routes makes it possible to harmoniously combine travel and exploration with the conservation of nature and cultural heritage [16]. The routes created are dynamic characters and can be updated and complemented with new data according to city traffic changes, tourist demands, and atmospheric conditions [17].

2. Materials and Methods

The city of Faro is the capital of the Algarve, located further south in the territory. According to the Köppen–Geiger classification, the climate is Csa (Mediterranean with dry and hot summers). The average temperature is 18°, and the average precipitation is 499 mm, with around 3428.54 h of sunshine throughout the year [18]. The city's orography is practically flat, with an average elevation of 20 m.

According to the 2021 Census [19], Faro has 67,622 inhabitants, and in the summer, due to tourism, the population increases considerably. Figure 1 displays the urban boundary of Faro along with the corresponding communication routes providing access to the 54 points of architectural interest. Table 1 shows the name of each monument represented in Figure 1.

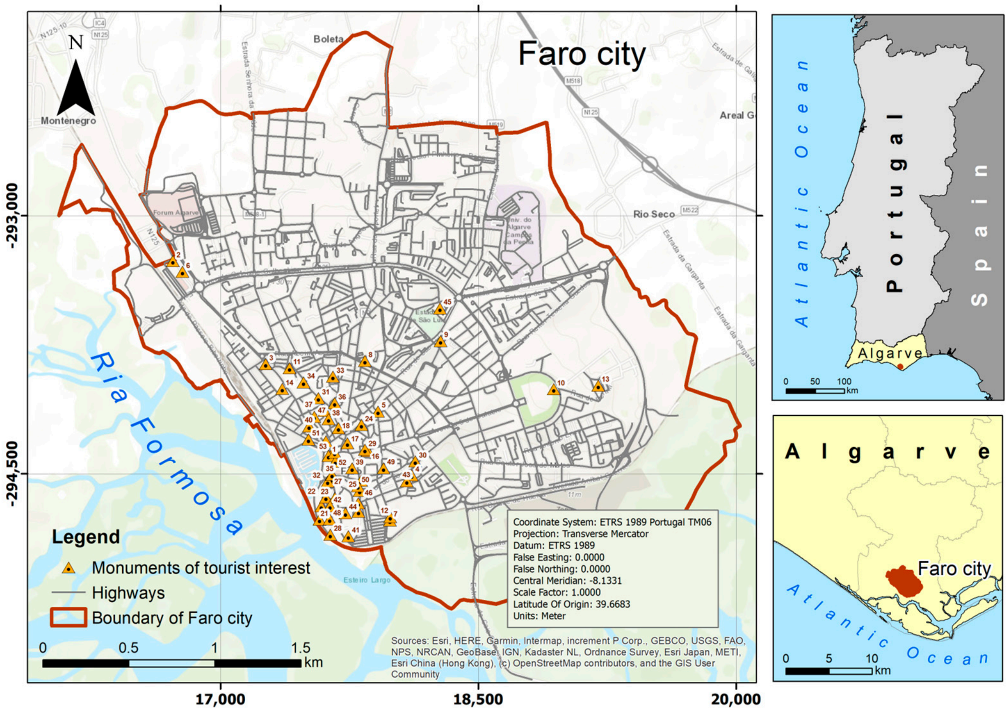

Figure 1. Urban area of Faro (Algarve, Portugal) (Source: The authors).

Table 1. Names of the monuments.

Id	Name	Id	Name
1	Bandstand	28	Revelim
2	House of Figures	29	Açafatas House
3	Mateus da Silveira House	30	Chapel of N. Sra. do Pé da Cruz
4	Seventeenth-century Fence	31	Normal Primary School
5	Lethes Theatre	32	Civil Government
6	Chapel and Horta do Ourives Farm	33	Church of N. Sra. do Monte do Carmo
7	São Francisco Convent	34	Santo António dos Capuchos Convent
8	Chapel of N. Sra. da Esperança	35	Church and Hospital of Misericórdia
9	Chapel of São Luís	36	Mother Church of São Pedro
10	Chapel of Santo António do Alto	37	Compromisso House
11	Chapel of São Sebastião	38	Lamprier House
12	Church of Ordem Terceira de S. Francisco	39	Montepio dos Artistas House
13	Fialho Palace	40	House of Tenente João de Carvalho
14	Guerreirinho Palace	41	Castle/Brewery
15	Byzantine Towers and Walls	42	Faro Cathedral
16	Pantojas Manor House	43	Barn of the Horta de S.Francisco
17	Gárfias Manor House	44	N. Sra. da Assunção Convent

Table 1. *Cont.*

Id	Name	Id	Name
18	Capitão-Mor Manor House	45	Jewish Cemetery
19	The Episcopal Seminary of S. José	46	Scissor-roofed House (16th-century)
20	Chapel of N. Sra do Repouso	47	Crispim House/District Archive
21	Porta Nova	48	House of Captain Manuel de Oliveira
22	Episcopal Palace	49	Arouca House
23	Town Hall	50	Consulate of Brazil
24	Doglioni Palace	51	Customs House
25	Belmarço Palace	52	Bank of Portugal Palace
26	Bivar Palace	53	Café Aliança
27	Arco da Vila/Chapel of N. Sra. do Ó	54	18th-century Building

The city of Faro has a rich historical heritage dating back to the 4th century BC, characterized by influences from various Mediterranean civilizations such as the Phoenicians, Romans, Visigoths, Moors, Christians, and Jews. These influences are evident in the city's architecture, from small chapels to grand palaces, showcasing the following:

Faro Cathedral, built upon a sequence of ruins (Christian medieval church, mosque, and Roman temple), blends various architectural styles, including Gothic, Mannerist, Portuguese Chã style (16th–17th century), and Baroque [20] (Figure 2a). Several Manueline-style chapels of the 14th to the 15th centuries are scattered around the city. An example is the Ermida do Santo António do Alto, built in the second half of the 15th century and added to a Gothic-medieval watchtower from the 14th century [21] (Figure 2b). The Fortress of Faro, dating back to Roman occupation in the 1st and 2nd centuries and expanded during the Arab conquest in the 9th century, features a Ravelin to the south constructed during the reign of D. Sebastião (1557–1578), designed to defend the city against sea invasions [22] (Figure 2c).

Nossa Senhora da Esperança Chapel, built in the 15th century and restored after the 1755 earthquake, is characterized by Baroque style on the triumphal arch and Rococo style on the dome [23] (Figure 3a).

Nossa Senhora da Assunção Convent, whose construction began in 1519, presents Renaissance architecture, incorporating a Manueline church and a Baroque dome [24] (Figure 3b).

Episcopal Palace, dating back to the 16th century, displays a blend of Gothic, Renaissance, and Baroque architectural styles [25] (Figure 3c).

Several typical XVI-century urban houses named Telhados de Tesoura (scissor-roofed). For example, Casa Quinhentista at Alexandre Herculano street [26] (Figure 3d).

The fence, named Cerca Seiscentista built in the 17th century, surrounded the city to defend it against Spanish invasions [27] (Figure 4a).

The barn called Celeiro da Horta de São Francisco, built in the 17th century, displays a mix of Baroque and Rococo agricultural architecture [28] (Figure 4b).

The Casa das Figuras was built in the mid-18th century in the peri-urban area of Faro. Originally, it served as an agricultural warehouse. Its façade is adorned with an indigenous person embracing mythical animals, symbolizing an allegory to the African and American continents [29] (Figure 4c).

The Jewish Cemetery, dating from the 19th century, shares similar characteristics to those found in the cemeteries of Morocco's Sephardic community [30] (Figure 4d).

The Arco da Vila and several neoclassical palaces [31] (Figure 5a).

A Bandstand was built in the late 19th century, featuring Italian neoclassical architecture [32] (Figure 5b).

Several Revivalist palaces and buildings with 20th-century bourgeois characteristics, such as the Bank of Portugal Palace, built in 1926 with tile ornamentation following neo-Arab patterns [33] (Figure 5c), or the Belmarço Palace, built between 1912 and 1917, with similarities to the buildings on Avenidas Novas in Lisbon, designed by the same architect, the illustrious Manuel Joaquim Norte Júnior (1878–1962) [34] (Figure 5d).

Figure 2. (**a**) Faro Cathedral, (**b**) Ermida of Santo António do Alto, (**c**) Fortress of Faro/Ravelin (Source: The authors).

Figure 3. (**a**) Nossa Senhora da Esperança Chapel, (**b**) Nossa Senhora da Assunção Convent, (**c**) Episcopal Palace, (**d**) Casa Quinhentista (Source: The authors).

This study's methodology was developed using GIS tools to select the optimal routes for accessing places of architectural interest in Faro.

The routes of the municipality of Faro were obtained using the QGIS 3.34 OpenStreetMap plugin and were then converted into a shapefile. The routes were georeferenced in the ETRS89-TM06 coordinate system, based on the Bing Maps orthophoto map, and limited to the urban area of Faro as defined by the Geographic Information Referencing Base (BGRI) of the 2021 Census. Based on the information available on the Camara Municipal of Faro website (https://www.faro.pt/menu/903/cidade-de-faro.aspx, accessed on 1 June 2024) and using a Global Navigation Satellite System (GNSS) receiver in Real-Time Kinematic (RTK) mode, the locations of Faro's architectural monuments were obtained.

The coordinates obtained for the monuments were corrected with a horizontal precision of 2.5 cm and a vertical precision of 5 cm, using Leica's HxGN SmartNet network reference station at the Institute of Engineering, University of Algarve.

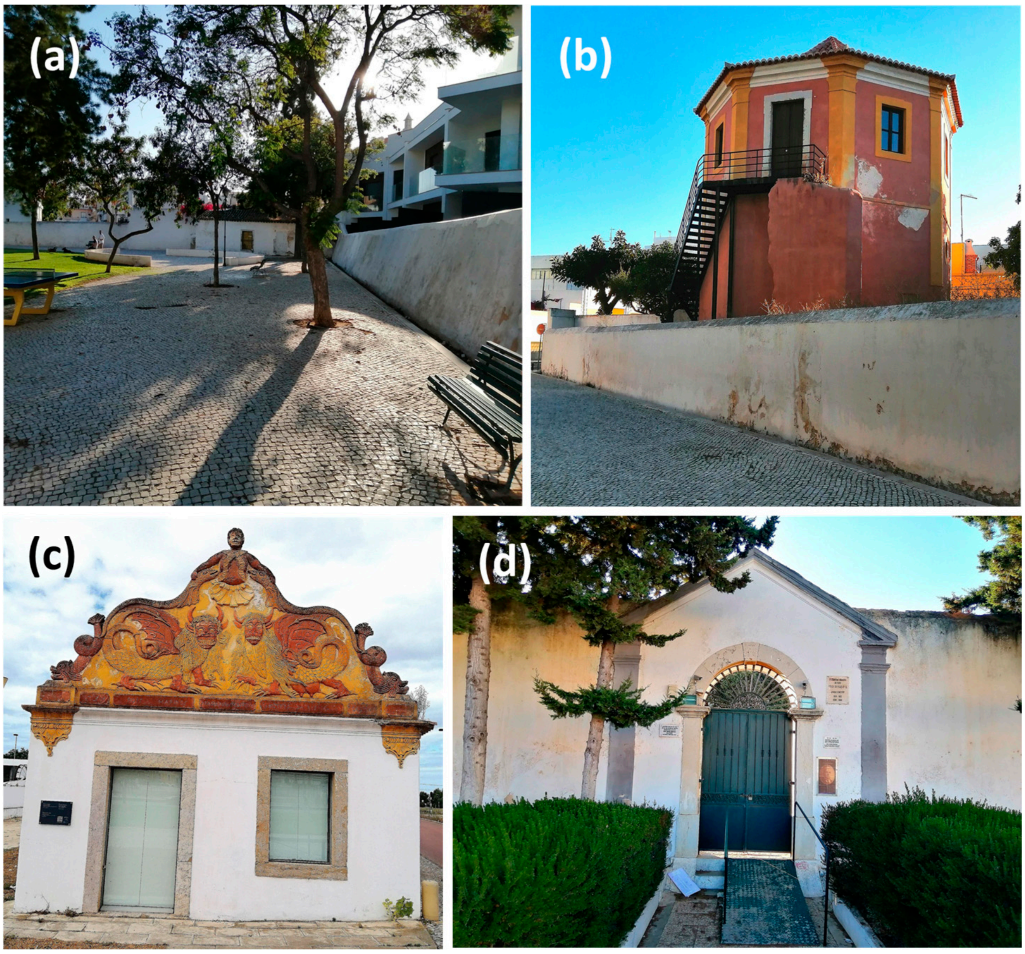

Figure 4. (**a**) Cerca Seiscentista, (**b**) Celeiro da Horta de São Francisco, (**c**) Casa das Figuras, (**d**) Jewish Cemetery (Source: The authors).

The file containing monument coordinates in ETRS89-TM06 was converted to a shapefile. In ArcGIS, the files containing urban roads and monuments from Faro were converted into feature classes within a personal geodatabase. A network dataset was created using the feature class of urban roads with an "endpoint" connectivity policy. The cost function used was "distance", and the mode of transport was an e-scooter. Three sets of visiting points were defined: 54 monuments refer to the number of architecturally interesting monuments within the city, 31 monuments are in the city center (old town), and another set of 24 monuments is situated outside the old city.

In the attribute table of urban roads in Faro, two attributes were defined: from the start node to the end node and from the end node to the start node. In cases where the direction was not permitted, the attribute received a value of −1; otherwise, it was filled with the distance value of the road edge.

The spatial analysis of the 54 existing monuments in the city was conducted using the Network Analyst extension for ArcMap 10.8, developed by Esri, Redlands, CA, USA. This tool enables the complex analyses of transportation and service networks. With Network Analyst, users can model, analyze, and visualize transportation networks to gain insights into route accessibility and efficiency, define service areas, optimize locations, and address logistical challenges [35].

Figure 5. (**a**) Arco da Vila, (**b**) Bandstand, (**c**) Bank of Portugal Palace, (**d**) Belmarço Palace (Source: The authors).

One of the features of Network Analyst is accessibility analysis using the Origin-Destination Cost Matrix tool. This matrix, which defines the minimum distances between monuments, allows us to determine (i) the diameter of the network, which represents the distance between the furthest pair of monuments (Equation (1)); (ii) the center of the network, which is the monument for which the maximum distance to the furthest monument is minimum (Equation (2)); and (iii) the median or centroid of the network, which is the monument that minimizes the sum of distances to the remaining monuments (Equation (3)). After this analysis, a monument was designated as the starting point for all defined routes.

$$D(G) = max[d(u,v)], \quad \forall\, u,v \in V \tag{1}$$

where $D(G)$ is the diameter of network G and $d(u,v)$ is distance between the vertices u and v within the set of vertices V.

$$C(G) = min\left[\sum_{j=1}^{n-1}\left(d\left(u_0, v_j\right)\right)\right], \quad \forall\, u_o, v_j \in V \tag{2}$$

where $C(G))$ is the center of network G, n is the number of vertices in the set V, u_0 is the origin vertex, and v_j is the destination vertex.

$$M(G) = min\left[max\left(d\left(u_0, v_j\right)\right)_{j=1,\,\ldots,n-1}\right], \quad \forall\, u_o, v_j \in V \tag{3}$$

where $M(G)$ is the median (or centroid) of network G.

The proximity of the monuments to the center and centroid was analyzed by mapping the proximity areas using the Service Area tool of the Network Analyst extension in ArcMap 10.8. This analysis considered Facilities Distances with intervals of 200 m and a maximum distance of 2 km.

The best routes to visit the monuments were implemented using the route analysis tool of the Network Analyst extension in ArcMap 10.8, which utilizes the Dijkstra algorithm [36].

Dijkstra's algorithm is a method for finding the shortest path from a source vertex to all other vertices in a graph. The method uses an adjacency matrix where the rows and columns correspond to the vertices. Each entry in the matrix contains the cost of the edge connecting two vertices. It is divided into two steps: initialization and iteration. In the initialization step, a set S is defined to represent the vertices of the shortest path, initially containing only the source vertex I. In the adjacency matrix, the diagonal value for vertex I is set to 0, and for all other vertices, it is set to infinity. During the iteration process, the vertex with the lowest cost from vertex I is selected and added to the set S. The diagonal values in the adjacency matrix are updated only for vertices adjacent to I. This procedure is repeated, starting with the newly added vertex in S, and the cost values in the matrix are updated. The algorithm terminates when all vertices have been visited. The set S will contain the values cost and the sequence of vertices representing the minimum cost path to vertex I [37].

The routes were defined according to the following criteria: (i) Impedance is the length of the edge. (ii) Reorder the stops to find the optimal route while maintaining the initial and final stops. (iii) U-turns are permitted only at dead ends. (iv) Find network stop positions (near architectural monuments); searches were conducted with a 100 m tolerance and always adjusted to the nearest monument.

The available scooters in Faro have a maximum speed of 25 km/h [38]. However, it was considered that a safe speed for both the scooter riders and pedestrians would be 15 km/h. Therefore, this speed was chosen for traveling between monuments when using a scooter. The possibility of the visit being made on foot was also considered, assuming that the average walking speed of a person is 3 km/h. The study also considered that the visits would only be to the exterior of the monuments (free of charge), so we considered a 5 min stop at each monument, sufficient for appreciating the architectural aspects and taking some photographs.

The estimation of carbon reduction was based on the carbon emission data for various modes of transport published in 2022 in "The New Mobility Times" from the Lufthansa Innovation Hub [39]. This publication considered direct emissions and the entire lifecycle of each mode of transport, including manufacturing, maintenance, wear, energy consumed during use, and emitted carbon. More specifically, data for the transport used in the city of Faro were utilized, namely gasoline cars with a total carbon emission of 209.9 g/km, diesel cars with a total emission of 205.1 g/km, dockless e-kick scooters with a total of 102.0 g/km, and walking with zero carbon emissions.

3. Results

Figure 6 shows Faro's network dataset, characterized by a connected structure with a total length of 143 km. The dataset includes 2095 nodes (junctions) and 2912 arcs (edges), with an average arc length of 49 m. The degree to the input and output of junctions has a maximum value of 2. The impedance associated with each edge corresponds to the distance from the edge.

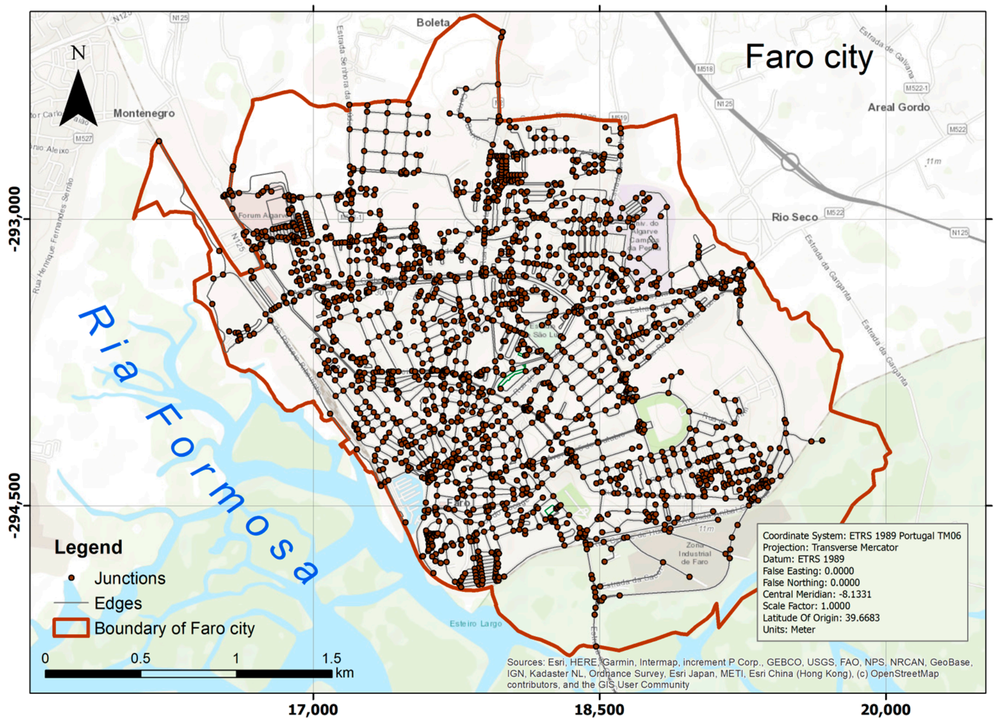

Figure 6. Network dataset of Faro (Source: The authors).

The lines of the origin–destination cost matrix are presented in Figure 7. The network's diameter is 3.141 km, corresponding to the distance between the farthest monuments (Casa das Figuras and Fialho Palace). The centroid of the network is the Bandstand, and the center is the Chapel of Nossa Senhora da Esperança.

Based on the results of the Facilities Distances (Figure 8), it can be observed that the Chapel of Nossa Senhora da Esperança (located in the center) has a distance between 0.4 km and 1.2 km to 46 monuments. Only seven monuments have Facilities Distances that are greater than 1.4 km.

Regarding the Bandstand (located in the centroid), the Facilities Distances vary between 20 m and 1 km to 48 monuments, with only five being at Facilities Distances greater than 1.4 km.

The Bandstand was primarily selected as the starting point due to its proximity to the monuments, making it a strategic choice for visitors to explore the city's historical attractions. However, its central location near the bus terminal, its adjacence to the marina and the dock for beach access, and its proximity to various hotels also contributes to its importance as an initial reference point for visitors.

Figure 9 shows the optimal route to visit all the monuments. The total route covers a total distance of 17.35 km. If the tourist chooses to use an electric vehicle at an average speed of 15 km/h, with stops of 5 min for each monument, it takes about 5 h and 40 min. Based on the study by Kolin Schunck [39], it was found that for the route mentioned above, using an e-scooter instead of other means of transport results in a significant reduction in carbon emissions. Using an e-scooter instead of a diesel car, the carbon emission savings are 1789 g/km per person. The reduction is even greater than a gasoline car, totaling 1872 g/km. Compared to a bus, the e-scooter saves 179 g/km in carbon emissions. If the tourist travels on foot at an average speed of 3 km/h, the same route with stops every 5 min at each monument will take approximately 10 h 17 m. In this case, where the carbon emission is zero, there is a reduction of 3642 g/km if the trip was made by a gasoline car, 3558 g/km if made by a diesel car, and 1948 g/km if made by bus. This last option may be feasible for young people. However, it is recommended that tourists stay in the city for at least two days to enjoy the visit calmly.

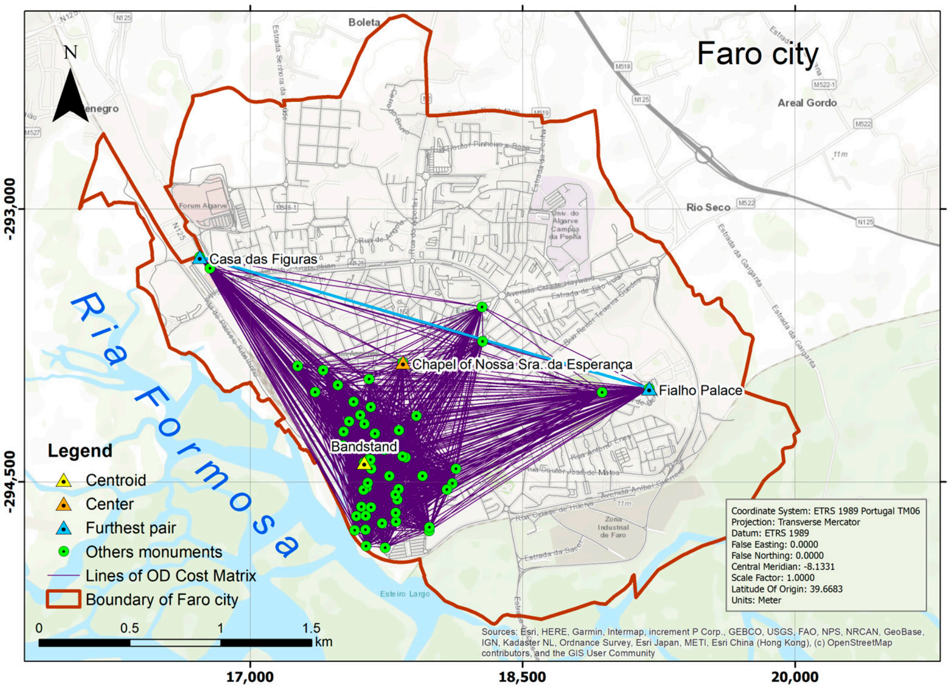

Figure 7. Origin–destination cost matrix (Source: The authors).

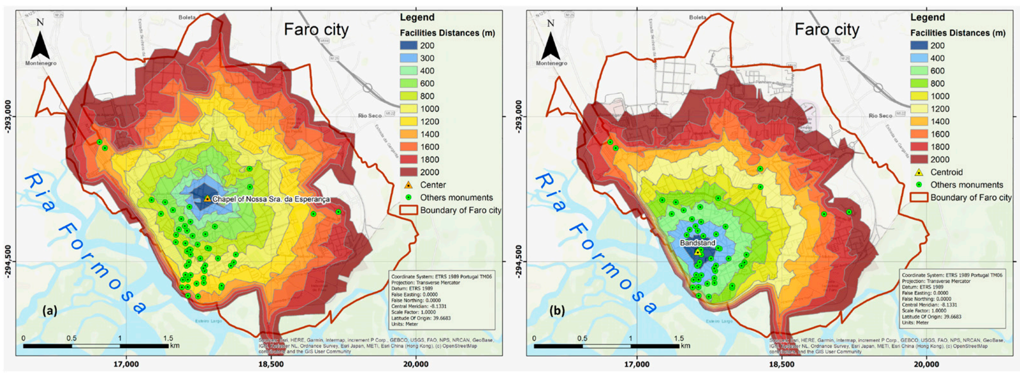

Figure 8. (**a**) Facilities Distances to the Chapel of Nossa Senhora da Esperança and (**b**) Facilities Distances to the Bandstand (Source: The authors).

If visits to historical monuments are divided into two routes, both starting from the centroid (Bandstand), one including the 31 monuments located in the city center (old part of the city) and the other including the 24 monuments in the outer part of the city, the optimal closed-circuit routes found measure 6.16 km and 11.31 km, respectively. Figures 10 and 11 show the optimal routes to visit the 31 and 24 monuments, respectively. If the tourist chooses to visit 31 monuments using an electric vehicle, it will take 3 h and results in a carbon reduction of 665 g/km compared to a gasoline car, 635 g/km compared to a diesel car, and 63 g/km compared to a bus. If they travel on foot, they can visit these monuments in 4 h and 45 min and the carbon reduction is 1293 g/km compared to using a gasoline car, 1263 g/km compared to a diesel car, and 692 g/km compared to a bus. To visit the 24 monuments, tourists can do so in 2 h and 45 min if they travel by electric vehicle, reducing carbon emissions by 1220 g/km compared to a gasoline car, 1166 g/km compared to a diesel car, and 117 g/km compared to a bus. In case of walking by foot, it takes 5 h and 45 min, reducing carbon emissions by 2374 g/km compared to a gasoline car, 2320 g/km compared to a diesel car, and 1270 g/km compared to a bus.

The two routes presented can be divided into smaller routes, allowing tourists to dedicate more time to specific monuments and opt for guided tours inside. This way, tourists can stay longer in the city and enjoy its architectural richness, the magnificent beaches of the barrier islands that constitute Faro's coastline, and its gastronomy.

Figure 9. Optimal route to visit 54 monuments (Source: The authors).

Figure 10. Optimal route to visit 31 monuments (Source: The authors).

Figure 11. Optimal route to visit 24 monuments (Source: The authors).

4. Discussion

The tourist routes divided by geographic zones can promote local economic development by encouraging the rehabilitation of buildings and the growth of businesses, such as restaurants, shops, and hotels [40].

In the study conducted in the Lushunkou district of China (512 km^2), Pei et al. [41] utilized the Cost Allocation tool from the Spatial Analyst Tools module in ArcGIS to zone 181 tourist areas associated with 217 tourist sites. The monuments were categorized according to their popularity and attractiveness, and different time limits were applied to visits. The traffic cost of the tourist routes was calculated based on three criteria: distance, speed, and time, while also considering the available visiting times.

In the study focusing on the monuments of Faro, specific tourist zoning was not implemented. However, when defining the two routes for visiting the 31 and 24 monuments, the area was empirically divided into two geographical regions: the route with 31 monuments, which is denser and situated in the historic city center, and the route with 24 monuments, which is more dispersed and located in the surrounding areas. Since Faro is a medium-size city (7.1 km^2), the Cost Allocation tool was not employed to zone these areas. Furthermore, the monuments were not categorized based on popularity or attractiveness, and visiting times were not taken into account, as visits are limited to the exteriors of the monuments, with a duration of 5 min per visit. The street directions were only defined for e-scooter trips, and the traffic cost was calculated based on the distance traveled, not considering the speed and time, given that the amount of traffic does not influence e-scooter and on-foot travel.

In future work, we intend to carry out a study similar to the one conducted by Pie et al. [41] but in the municipality of Faro, which covers an area of approximately 200 km^2. For this study, using tools such as Cost Allocation to divide up tourist service areas would be pertinent. In addition, an approach based on creating personalized tourist routes, as proposed by Xu et al. [42], will also be considered, as it could make valuable contributions to tourism development in the region.

The routes created in Faro did not address critical issues such as degraded pavements, narrow sidewalks, and the needs of tourists with mobility and vision impairments. While some improvements have been made, such as lowering curbs with ramps, as discussed in the study by Rosa et al. [43], further requalification is needed. Simultaneously, there is a noticeable lack of order and care among e-scooter users, such as improper use, scooters being abandoned on sidewalks, roads, near building entrances, or leaning against parked cars, disregard by drivers' in other vehicles and by pedestrians, accidents, and vandalism. The public security forces should enhance enforcement and monitoring to address these issues. Additionally, stakeholders should establish designated parking areas for e-scooters, as suggested by Granja-Martins and Fernandez [44], to help mitigate the problem of improper parking.

Regarding CO_2 emissions, the study reveals that using e-scooters on tourist routes in a medium-sized city like Faro contributes to reducing CO_2 emissions. However, other studies indicate that using these vehicles per passenger can increase CO_2 emissions compared to different modes of transport, including private cars, given that e-scooters have short life cycles [45,46]. E-scooters are predominantly made of aluminum and equipped with lithium-ion batteries. The manufacturing of these materials significantly contributes to carbon emissions into the atmosphere. Furthermore, the transportation of e-scooters to their areas of use and the logistics associated with their maintenance and battery charging are typically carried out by service vehicles that use fossil fuels, significantly contributing to the carbon footprint [46]. According to Hollingsworth et al. [47], e-scooter manufacturers should use green aluminum in their production, made from recycled material and produced using renewable energy. Additionally, they propose designing lighter e-scooters to reduce the carbon emissions associated with their manufacturing.

Based on the measures proposed by Hollingsworth et al. [47], the municipality of Faro, when integrating the use of e-scooters into tourist mobility, should reinforce the following specific policies to reduce the environmental problems associated with their use: (i) allow loaded and partially loaded e-scooters to remain on the public highway overnight, thus reducing the carbon emissions associated with their collection, (ii) establish anti-vandalism policies to reduce the misuse and poor maintenance of e-scooters to avoid a short lifespan; (iii) require the companies that provide the scooter sharing service to adopt centralized management to coordinate the collection and distribution operations of e-scooters to optimize routes and schedules. This will mean that these tasks will no longer be carried out independently by each operator, reducing the amount of travel.

Service providers can also adopt measures to reduce CO_2 emissions, such as using more efficient vehicles in distribution/collection and creating solar battery charging infrastructures [48] to allow users to exchange and charge the battery, thus eliminating collection travel.

5. Conclusions

Optimizing tourist routes represents a significant challenge for sustainable cities.

The application of GIS to optimize these routes in the city of Faro using e-scooters and walking represents a significant advance for the sustainable development of urban tourism. The mapping of routes, considering the time and distance required to visit 54 historical monuments using e-scooters and walking, has improved visitors' experiences and significantly contributed to reducing CO_2 emissions. This approach promotes healthier and greener tourism, aligned with environmental sustainability objectives.

The route optimization used ArcGIS with the Network Analyst extension and vector data sourced from OpenStreetMap. The results showed that it is possible to plan routes that can be completed in one or more days, adapting to visitors' availability, physical capacity, and mobility preferences. The ideal route to visit the 54 historical sites forms a closed loop with a distance of 17.35 km. If the tourist uses an electric vehicle at an average speed of 15 km/h, with stops of 5 min at each monument, it takes about 5 h and 40 min. If opting to travel on foot at an average speed of 3 km/h, the same route with 5 min stops at each monument will take approximately 10 h and 17 min. When divided into two routes, one with 31 monuments in the old city and another with 24 monuments in the outer area of the urban center, the optimal routes measure 6.16 km and 11.31 km, respectively. If tourists choose to visit the 31 monuments using an electric vehicle, it will take 3 h. Opting to walk will allow them to visit these monuments in 4 h and 45 min. Tourists can visit the 24 monuments in 2 h and 45 min by electric vehicle and in 5 h and 45 min on foot. It should be noted that the optimal routes were efficiently defined in terms of time and distance; however, critical points were not addressed, particularly concerning accessibility and degraded infrastructures. This study provides insight into sustainable planning actions, the methodology of which can be applied to other heritage destinations worldwide.

In the future, there is an intention to achieve even more precise route optimization by incorporating the effects of topography, temperatures at different times, and seasonal variations, similar to what was conducted in the pilot study conducted in the historic center of Thessaloniki, Greece [49]. Additionally, there is a plan to include the planning of personalized routes for each visitor by creating an intelligent system implemented in a mobile application.

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