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RESEARCH ARTICLE

Exploring Daily Tour Routes in Historical Peninsula by Using Generative Design

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ABSTRACT

In this study, with the help of a generative design, daily routes were created and optimized in light of certain objectives within the scope of the Historical Peninsula of Istanbul, especially in areas containing monumental structures and defined as world heritage sites. The current cultural-historical tours in the historical peninsula mainly focus on the main points such as Sultanahmet Square and its surroundings, Topkapı Palace and its surroundings, and the Grand Bazaar. However, within the scope of the peninsula, approximately 12,000 registered buildings (Istanbul Historic Peninsula Management Plan, 2018) are located on the Marmara Walls on the seven hills line, Land Walls, Golden Horn shores, and in each sub-region within its own urban texture. In this context, it is aimed to reveal the different route potentials within the protected areas that should be seen in the peninsula as a whole. In the study, road widths and topographical data which are two of the important parameters that constitute the original texture, and the areas that need to be seen at distances that can be visited daily were taken into consideration. In the whole historical peninsula, 9 different sightseeing routes were determined, the starting point of these routes and one mandatory stop for each route were defined, and the routes were optimized with single-objective optimization for walkability and exploration of the historical texture as much as possible. With this method, a decision support tool is provided for decision-makers such as city planners, tour guides, and travelers themselves.

Keywords: İstanbul Historical Peninsula, generative design, single objective optimization, decision support tools

Introduction

The Historical Peninsula has been the subject of studies from many different perspectives in the historical process with its historical, cultural, and natural qualities. The diversity offered by the area, its quantitative values, its spatial size, population density, and mobility bring up many potentials as well as problems that need to be solved.

The Historic Peninsula, with its residential areas, working areas, and especially the only center of the metropolitan area until the 1960s (the area where the traditional center is located today) has precious monumental buildings, civil architecture examples, and silhouettes due to its topography. These areas need to be protected and these are the points that should be seen for tourism in this context. In the Peninsula, there exist many tourism and promotion routes that have been determined both by the relevant municipality, various institutions, and non-governmental organizations. These routes are predominantly around certain monumental buildings and their surroundings but may be limited to Topkapı Palace, Hagia Sophia, and Sultanahmet. Apart from these routes, there exist also thematic sightseeing routes organized in the area.

However, these routes cannot be diversified according to user preferences and are not customized according to the user's accessibility ability or the regions they want to focus on.

In this study, a methodological experiment was carried out to create new routes that are customized by decision-makers in the Historic Peninsula. These routes mainly take into account the World Heritage sites but also integrate the heritage sites and other must-see points of the peninsula. The research question of this study can be summarized as "To create the ideal route specific to the demands of the decision-maker, with the help of decision support tools; the decision of which destinations and paths to be used is made, and alternatives are generated." In this method experiment, Geographical Informations Systems, and generative design tools were used by the decision maker to identify potential sightseeing destinations and create optimal routes under desired

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conditions. The features of road structure according to road width and slope were identified with GIS and after, these attributes of roads were used for generating potential routes between potential destinations.

Computational Design As A Tool For Decision Making

From the perspective of complex system theory, it can be said that cities are complex systems due to the intersection of subsystems like transportation, ecology, humans, infrastructure, and social systems (Alberti, 2008; Batty & Marshall, 2012). This complexity creates non-linearity, unpredictability, and numerous possibilities for various actors in the city (Portugali, 2018). In this context, decision-making becomes a hard process for decision-makers. Decision support systems help the decision-makers adapt to this complex process by data collecting, analyzing, visualizing, and creating fast, adaptable, flexible solutions. Decision support systems have the potential to significantly reduce the amount of time required to solve the problem, as well as decrease the amount of resources and materials that are wasted in the process (Chan et al., 2016). Although computer programs are the first thing that comes to mind when it comes to decision support tools, a computer-based system, human power, or a combination of them can be the decision support tool for the decision-maker. But mostly, Geographical Information Systems (GIS) and Computer Aided Design tools are the most commonly used computer-based decision support tools in urban-related problems.

Decision-making is defined as the process of finding the optimal solution for a goal (Sugumaran & Degroote, 2020). But in complex systems, finding an ideal can be hard with only human power and it needs computer science to manage this level of complexity. In this study, first of all, the existing structure of the urban layout was understood by using GIS, which is a decision-support tool, and then ideal solutions were produced by using computational design and AI-assisted optimization, which is also a decision-support tool.

Computational design is subdivided into many sub-headings, but parametric and generative designs are the most common terms used in the literature (Lee, 2015). They are often intertwined in the literature. For parametric design, it can be stated as designing the production process, not the product itself, by defining certain parameters and obtaining multi-alternative outputs (Lee, 2015). Thanks to the definition of these parameters, when the final product is not desired or when the condition changes, it allows individuals to quickly return to the design phase and produce new results suitable for the new condition. This fast adaptation capability makes parametric design valuable for solving complex problems. Generative design has very similar features to parametric design, but with a slight difference - it uses AI-based methods for optimization goals (*Generative Design 101*, n.d.). Thanks to the generative design, the options that are important for the decision-maker are identified in a very short time and suitable results are generated. In this way, the decision maker can reduce the total effort by shaping the process instead of producing the design one by one and they can have much more control over the possibilities by choosing among the solutions.

Methodology

As the traditional center of the Istanbul metropolitan area, the Historic Peninsula is not limited to the metropolitan area, it is Turkey’s most important tourism destination. In particular, the area between Atatürk Boulevard and Topkapı Palace on the east-west extension, the Sultanahmet and Hagia Sophia Mosques, and the Grand Bazaar area are known to both mass tourism and independent tourists. The defined area is especially preferred for one-night stays and covers a significant portion of the literature related to the peninsula. However, the historical and architectural values that must be seen, which belong to the entire peninsula, are not limited to this area. New cultural routes have been added in the recent historical process. With the studies conducted in the area, new values have been discovered (such as Yenikapı, cisterns, etc.), and with the restoration of monumental and civil architectural examples and street improvements, new potential routes have emerged in the area.

The availability of parking spaces and easy access using vehicles are important factors in the preference for these frequently visited places. However, visiting many places in the Historic Peninsula can only be possible on foot after a certain point. Walking in areas with a certain slope after exiting the metro, tram, bus, etc. stations public transport vehicles can be challenging and not preferred considering health and age status. Therefore, the topography and width of the roads were analyzed and became an input for binding many valuable destinations.

The aim was to create multiple routes to be visited and seen in the whole of the Historic Peninsula, focusing on the World Heritage Sites. To create these routes, especially the transportation and topography analyses of the area were made and alternative criteria were determined based on these analyses. In the relationship between topography and accessibility, it was aimed to create routes that can cover both the original texture of the area and the World Heritage Sites and other points to be seen. For this purpose, in this study, road width and the slope of the roads were determined as parameters of the design process. In this context, the existing transport infrastructure was analyzed according to road width and the slope of the road in the ArcGIS Pro program. Although the accessible road slope in the daily life of people is accepted as approximately 8%, the maximum slope that tourists can walk comfortably in long-term walks, considering different age groups, is stated as 5%. In this study, roads with a slope of 5% were determined as the upper limit for comfortable traveling, and areas with a slope of 5% and less than 5% were accepted as ideal roads in the design process. In addition, another parameter is the roads with widths of 5 m or less. Roads under 5 m wide are concentrated in the traditional texture of the peninsula, where both parcel size and civil architecture examples are concentrated. Roads with a road width of more than 5 m are considered as roads that are more comfortable to travel on as cars share the road with pedestrians in most of the peninsula.

After defining the road features, three scenarios were established with different starting points and mandatory destinations. A total of nine alternatives were created for these three scenarios based on the road features used in the travel routes. The alternatives generated for 3 different scenarios were i) maximizing the use of roads with a slope $\leq$ 5% and width >5 m, ii) maximizing the use of roads with a slope $\leq$ 55% and width $\leq$ 55 m, iii) the shortest path without any preferred road features. After structuring the algorithm, the alternatives were optimized by Rhino Grasshopper's Galapagos plug-in as single-objective optimization.

Overview of the Historical Peninsula

The province of Istanbul is located at the junction of the Asian and European continents, within the Marmara Region, one of the seven geographical regions of Turkey, and forms a transition between the Balkan Peninsula and Anatolia. It is topographically bounded by the Black Sea to the north, the high hills of the Kocaeli Mountain Range to the east, the Sea of Marmara to the south, and the water dividing line of the Ergene Basin to the west, and administratively by the provinces of Kocaeli to the east and Tekirdağ to the west. The Historic Peninsula is located between 41° 02' north latitude and 28°55'34 east longitude. Located at the southeastern end of the Çatalca Peninsula, the Historic Peninsula forms a unique geography shaping the entrances of the Bosphorus and Golden Horn to the Marmara Sea. The area is bordered by the Golden Horn to the northeast and the Beyoğlu coast to the south, the Sea of Marmara to the south, Eyüp to the north, Zeytinburnu to the west and Bayrampaşa to the northwest (Figure 1).

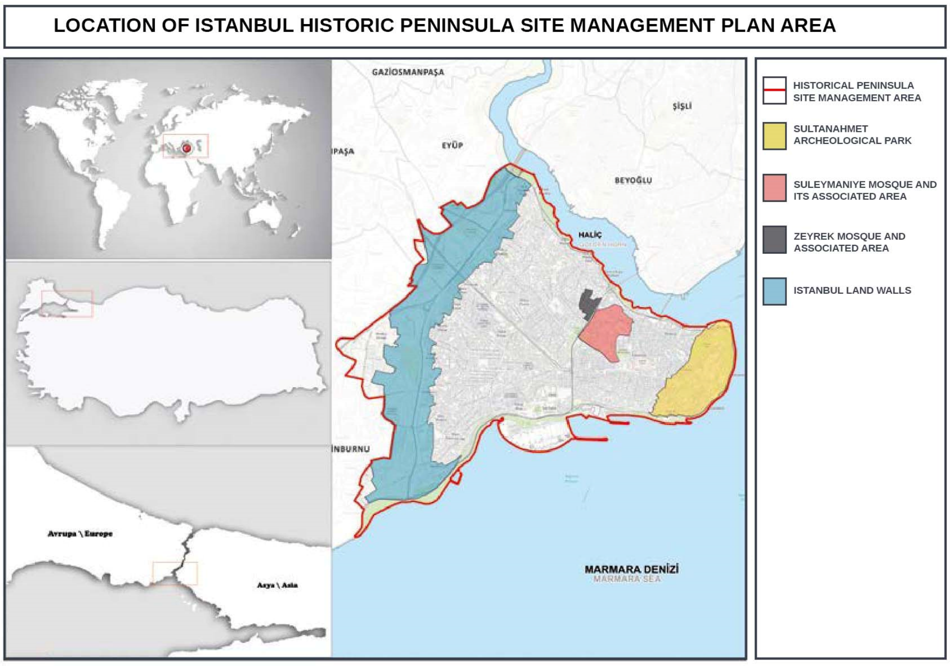

Figure 1. *Location of the Historic Peninsula Management Plan (Istanbul Historic Peninsula Management Plan, 2018)*

The Historic Peninsula as a whole, excluding the Yenikapı Embankment Area, is a protected area and its four World Heritage Sites were inscribed on the World Heritage List in 1985.

Areas in the Historic Peninsula on UNESCO's World Heritage List have been listed as:

- Sultanahmet Urban and Archaeological Conservation Area (The Archaeological Park)
- Süleymaniye Mosque and its Associated Conservation Area
- Zeyrek Mosque (Pantocrator Church) and its Associated Conservation Area

- Land Walls of Istanbul (Figure 2)

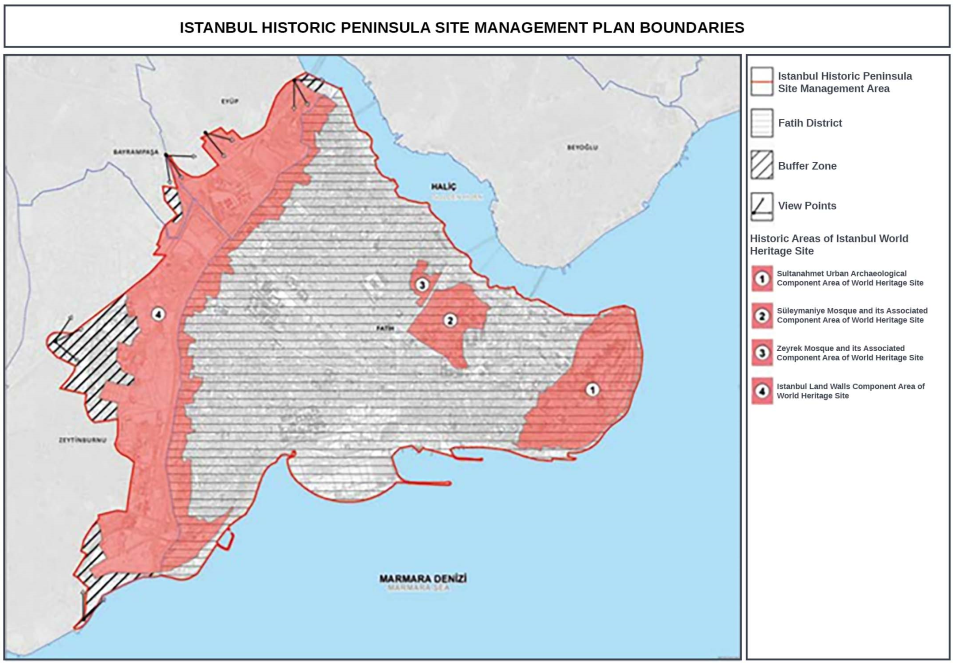

Figure 2. *Boundaries of Istanbul Historic Peninsula Management Plan (Istanbul Historic Peninsula Management Plan, 2018)*

Table 1. *Historic Peninsula Walled City Area (IMM,2018)*

Region	County name	Area (Ha)	Ratio (%)
Historic Peninsula Walled City	Fatih	1557	71.82
	Yenikapı Embankment Area	58	2.67
	Total	1615	74.49

The Historical Peninsula, as the study area, encompasses the entire Fatih District, with an area of 1,557 hectares, excluding the Yenikapı filling area. When considering this size and the densities of the night and day visitor population, functional areas, and transport transfer areas it exhibits a very dynamic and mobile structure. The night population of the area in 2022 was approximately 400,000, while the daytime population exceeded 2 million. In this context, the creation of routes to be traveled in line with the assumptions of the historical environment, which is the subject of the study, is challenging compared to relatively quieter historical environments. The presence of the most important and largest health, education, and administrative institutions and organizations in the metropolitan area and the entire of Turkey, cause vehicle and pedestrian traffic to overlap, making it difficult to create comfortable walking routes. This makes the search for more comfortable traveling routes with new technologies even more important.

Current Road Structure In Historical Peninsula

In the first stage, the current situation of the road structure was examined according to the road width and slope. First-stage analyses were made using the ArcGIS program. To calculate the slope of the road structure, firstly, areas with a slope of more than 5% were defined. Next, the current road structure and the areas with a slope of more than 5% were overlaid and the roads were divided according to this intersection. As a result, it has been seen that 72.5% of the road structure is located on areas with slopes under 5%.

In addition to the slope, road widths were also classified according to road width. First, roads with a width smaller or equal to 5 m, which have a historically rich texture, were determined. In the second part, roads with a width larger than 5 m, which are easy to travel on according to the defined pedestrian roads, were ascertained.

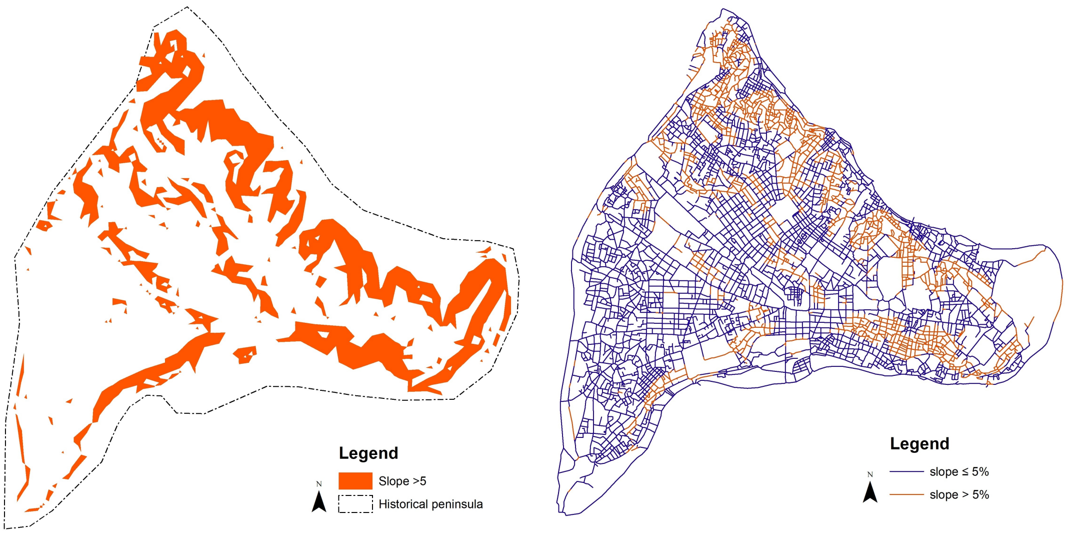

Figure 3. *Slope and road structure according to slope in Historic Peninsula*

Figure 4. *Road structure according to road width in Historic Peninsula*

As a result, the study found that 36.87% of the entire road network has ideal conditions for easier traveling, and 35.71% of them have ideal conditions for exploring the historical textures in the peninsula.

In the final stage of the study, the researchers applied an optimization study to prioritize the use of these roads in the generated routes.

Table 2. *Ratio of roads' features*

		ROAD WIDTH (%)	
		≥ 5	< 5
SLOPE (%)	≤ 5%	36.87	35.71
	> 5%	16.93	10.49

In the second stage, this road structure was used as input for route decision-making. To create the walking route, 14 main historical places were defined: Spice Bazaar, Grand Bazaar, Yedikule Fortress, Fener-Balat region, Samatya region, Kumkapı region, Süleymaniye Mosque, Beyazıt Square, Tekfur Palace, Bukoleon Palace, The Prison of Anemas, Kariye, Ayios Church region, Fatih Mosque, Zeyrek region, Sultanahmet region. These destination points were used in the algorithm as the potential destinations to select for generating optimized routes.

Figure 5. *Süleymaniye Mosque and Topkapı Palace (Istanbul Historic Peninsula Management Plan, 2018)*

Figure 6. *Fener Balat Region (Istanbul Historic Peninsula Management Plan, 2018)*

Figure 7. *Istanbul Land Walls and Yedikule Fortress (Istanbul Historic Peninsula Management Plan, 2018)*

To generate walking routes, three scenarios were decided on based on important historical destinations. The first scenario started at Yedikule Fortress and included The Prison of Anemas as a mandatory destination. The second scenario started at the Sultanahmet region and included the Sülemaniye region as a mandatory destination. In the last scenario, the Sultanahmet region was again chosen as the starting point, and the Fener-Balat region was the mandatory destination. These destinations were chosen for their historical significance and to create variety in the generated routes.

Algorithm

Finding the optimum option among the destinations and creating the most ideal route becomes a time-consuming and difficult process with human abilities alone. Therefore, at this stage, generative design was used as a support system for the decision-maker, so that alternatives that may be invisible to humans can be presented to the decision-maker in a very short time. Rhino's Grasshopper plug-in for the visualized algorithm was used as the generative design tool. First, destinations were defined in the program and then a random selection from these destinations was interpreted by the system as a parameter in the optimization. For random selection, a search space ranging from 4 to 8 on each route was determined. These numbers are an assumption taken from official travel routes in the Historical peninsula for an average travel route destination list. Then, to create the route between these stops, the road structure analyzed in the ArcGIS program was defined in Grasshopper with its features like slope and road width. The road structure, which was divided into 4 different classes according to slope and width, formed the input for the route creation. Between these destinations (with defined starting points), traveling routes were generated by selecting the shortest path. To determine the shortest path, the ShortestWalk plug-in was used which is a plug-in that includes the A* search algorithm. A* search algorithm is one of the heuristic AI algorithms that is mostly used in games or map applications for finding the shortest path. It is known for its calculating speed to generate fast results (Isaac computer science, n.d.).

Although the travel routes were created, the research question had not been fully explained, which was to find the "ideal" route based on both accessibility and comfort while exploring historical places. However, finding the best possible alternative in a complex urban system is generally a tough issue due to the need of controlling and calculating all parameters at the same time. This search process to find the optimum route with some constraints is generally named optimization (Küçükkoç, 2020). This process can be divided into two headlines according to their objectives: single-objective optimization and multi-objective optimization. In single optimization, the main goal is maximizing or minimizing the defined objective value with its constraints. On the other hand, multi-objective optimization deals with more than one objective. In this complexity, the best for one objective may be the worst for another, therefore, there can not be only one optimal goal in this optimization problem; there exists a set of optimal solutions (Sarker & Newton, 2007). In this study, the solution to the research question was generated as a single-objective optimization.

In the first stage, after identifying the features of the roads that were used by the generated exploring route, the maximization of the roads that will provide the most comfortable traveling experience was defined as the optimization problem. For this purpose, 3 optimization setups were made. First, roads with a slope smaller than or equal to 5% with a width larger than 5 m, which have the maximum percentage in the route for a comfortable journey, were selected. The experiment aimed to maximize the use of these roads by changing the number and locations of stops to be visited. Second, by using the defined mandatory stops, the question "Which destinations would be visited in the optimum shortest time without any road restrictions" was also optimized and alternatives were produced for the decision-maker. The final scenario was designed to enable maximum exploration of the historical structures of the peninsula, by using a road width smaller than or equal to 5m and a slope smaller than or equal to 5%.

Experiment Results

For 3 destination purposes, 9 different route optimizations were made in total. The first optimization group's obligatory destinations were defined as Yedikule Fortress and The Prison of Anemas, the latter of which is the starting point. Three different optimizations were made in this group. The first optimization in this group was defined as using a road slope less than or equal to 5% and a road width of more than 5 m while generating the alternatives. As a result, optimized route 1 selected 4 destinations: Yedikule Fortress, Bukoleon Palace, the Spice Bazaar, and the Prison of Anemas. The total length of the route was calculated as 11.2 km and the ratio of the slope was less than or equal to 5 and 73.5% of the roads had a width of more than 5 m. In addition to these destinations, even though the algorithm selected only 4 destinations, the traveling route is also fairly close to the Samatya region, Sultanahmet region, and Fener-Balat region. Thus, it can be said that this route contains 7 destinations.

The second optimization in this group was analyzed with the aim to maximize passing through narrow streets where the historical texture is dense. As a result, the route was calculated as 7.9 km. The proportion of roads with a slope less than or equal to 5% and a width less than 5 m was 49.4%. The proportion of roads with a slope is less than or equal to 5% and a width greater than 5 m was 34.7%. The destinations in this scenario were generated as the Prison of Anemas, the Ayios Church Region, the Samatya Region, the Fener-Balat Region, and the Yedikule Fortress.

The final optimization in this section was analyzed as an answer to the question "How would the mandatory stops of the first route be followed if they were to be reached in the shortest time without any road restrictions?" The route length was 6 km. The proportion of roads with a slope less than or equal to 5% and a width less than or equal to 5 m was identified as 48%; the proportion of roads with a slope less than or equal to 5% and a width greater than 5 m was identified as 34.4%. The destinations in this scenario were generated as Tekfur Palace, the Prison of Anemas, the Ayios Church Region, and Yedikule Fortress.

The second optimization group, the Sultanahmet Region was taken as the starting point and Süleymaniye Mosque as the mandatory destination. The optimization rules were determined like with optimization group 1. As a result, the first optimization destinations were determined as Topkapı Palace, Sultanahmet Region, Bukoleon Palace, the Grand Bazaar, Beyazıt Square, the Spice Bazaar, the Süleymaniye Region, and the Ayios Church Region. The route length was 13.3 km. The ratio of the road slope ≤5% and the road width of more than 5 m was 67%. In the second optimization, the route length was calculated as 10.1 km. The roads with a slope of ≤5% and a width of ≤5 m were 42%. This route's destinations are the Fener-Balat Region, the Ayios

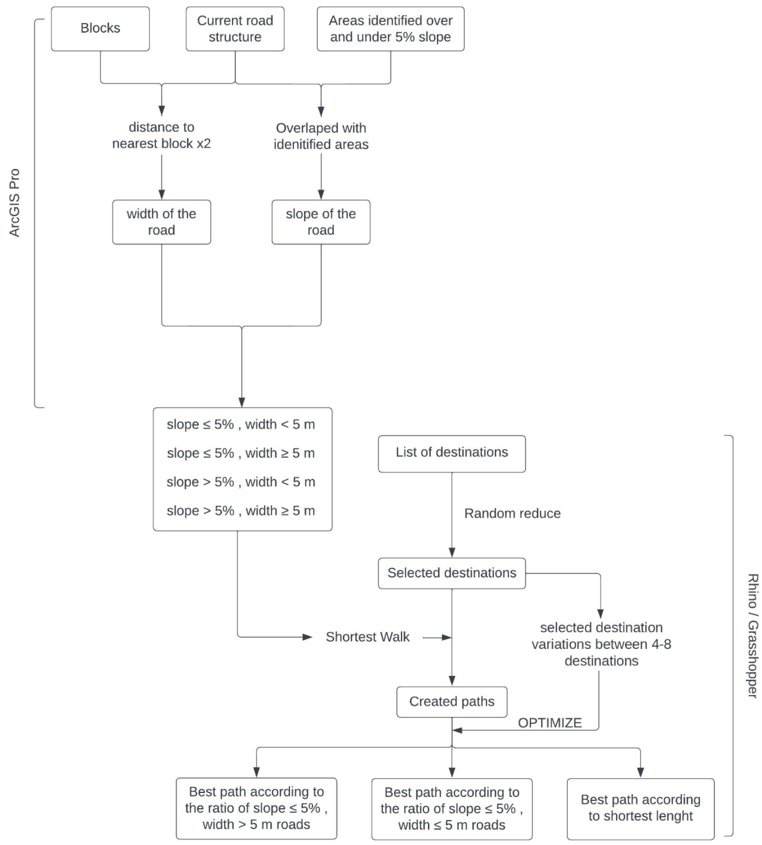

Figure 8. *The structure of the algorithm*

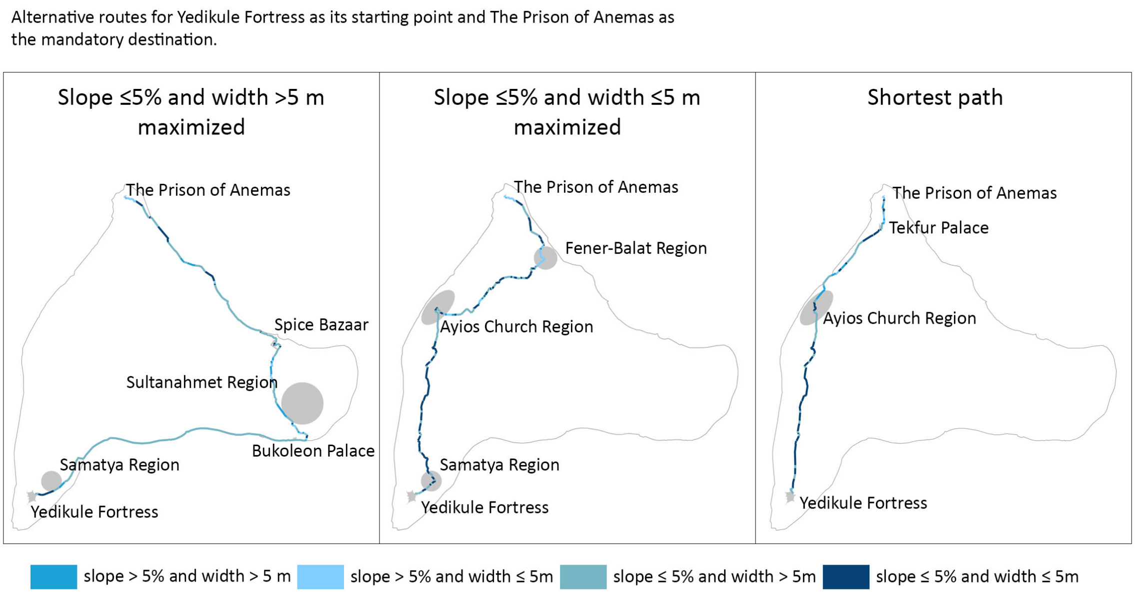

Figure 9. *Alternative routes for Yedikule Fortress as the starting point and the Prison of Anemas as the mandatory destination*

Church Region, the Samatya Region, Süleymaniye Mosque, and the Sultanahmet Region. In the last optimization, the route length decreased to 2.2 km and the destinations are Süleymaniye Mosque, the Grand Bazaar, Beyazıt Square, and the Sultanahmet Region.

For the last optimization group, the Sultanahmet Region was defined as the starting point with the Fener-Balat Region as the

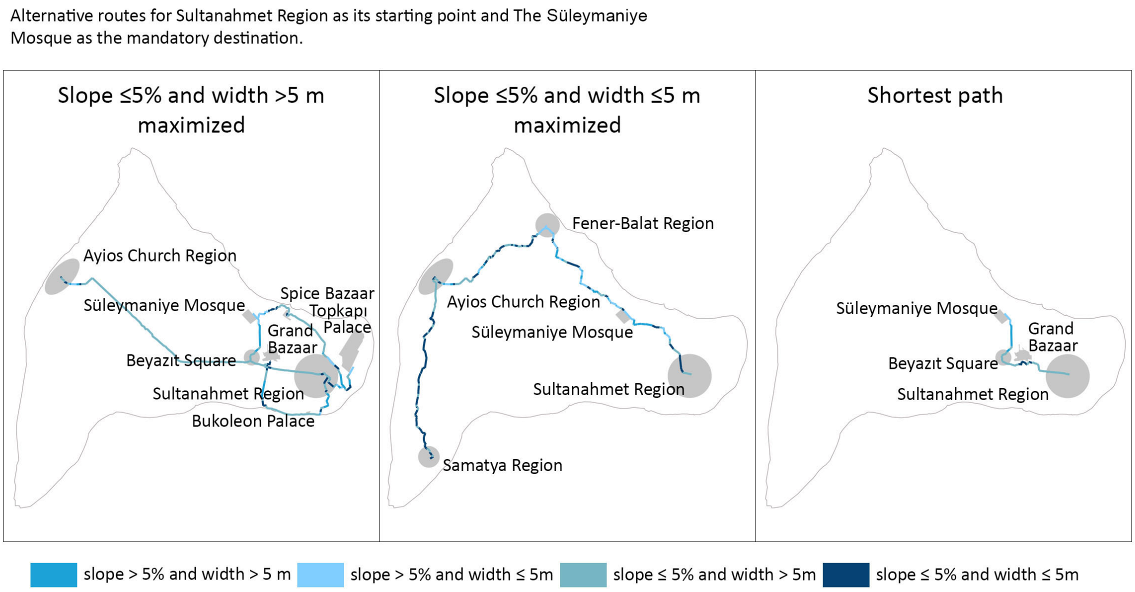

Figure 10. *Alternative routes for the Sultanahmet Region as the starting point and Süleymaniye Mosque as the mandatory destination*

mandatory stop. In the first optimization of this group, the length of the route was generated as 8.8 km. The ratio of the roads whose slope was smaller or equal to 5% and whose road width was more than 5 m was calculated as 76.9%. The destinations on this route are the Fener Balat region, the Fatih Mosque-Zeyrek Region, the Sultanahmet Region, and Bukoleon Palace. For the second optimization, the algorithm generated a 10 km travel route and determined the Fener-Balat Region, the Ayios Church Region, the Samatya Region, and the Sultanahmet Region as destinations. Roads with a slope ≤5% and width ≤5 m was 46.2%. In the final, shortest route optimization, destinations were defined as the Fener-Balat Region, the Fatih Mosque-Zeyrek Region, Beyazıt Square, and the Sultanahmet Region. In addition to this, because the Grand Bazaar is close to Beyazıt Square, it can be said that this route also includes the Grand Bazar with a little bit more effort. The length of this route was calculated as 4 km. The ratio of road slope ≤5% and width ≤5 m was 16% and road slope ≤5% and width >5 m was 69.4% in this route.

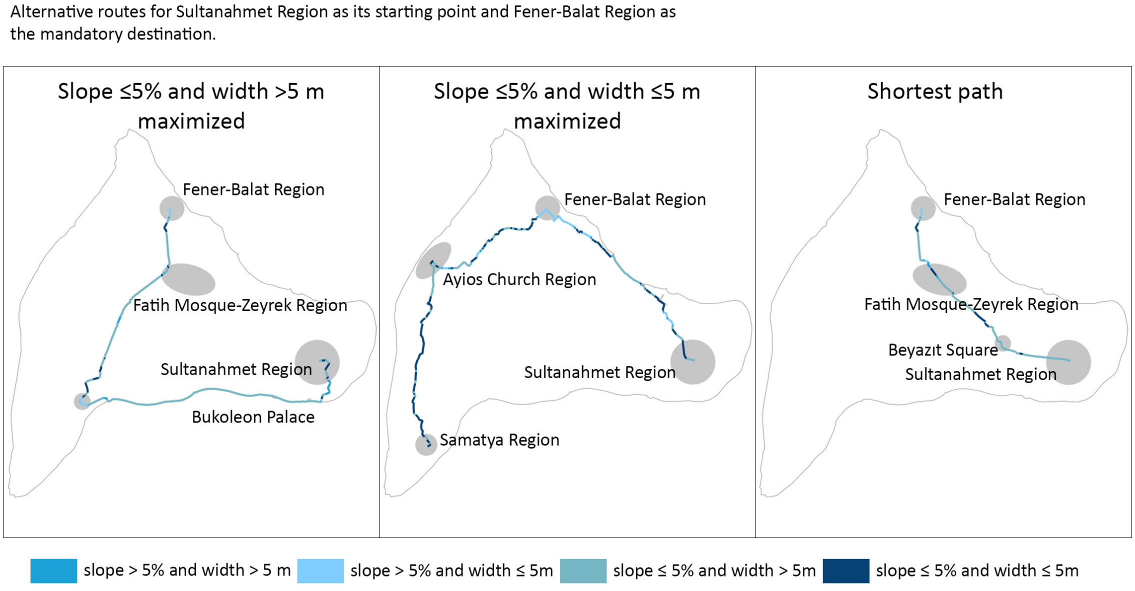

Figure 11. *Alternative routes for the Sultanahmet Region as the starting point and the Fener-Balat Region as the mandatory destination*

Table 3. *Summary of alternative routes*

	Group 1 (Starting point Prison of Anemas and Yedikule Fortress as obligation)			Group 2 (Strating point Sultanahmet Region and Süleymaniye Mosque as obligation)			Group 3 (Starting point Sultanahmet Region and Fener-Balat Region as obligation)		
	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path
Total length of the route (km)	11.2	7.9	6	13.3	10.1	2.2	8.8	10	4
Ratio of slope > 5% and width > 5m roads (%)	8.2	2.9	10.8	12.6	11	20.3	6	3.6	5.1
Ratio of slope > 5% and width ≤ 5m roads (%)	7.4	12.8	6.2	8.5	18.9	9.8	6.5	15.5	8.7
Ratio of slope ≤ 5% and width > 5m roads (%)	73.2	34.7	34.4	67.2	27.1	58.6	76.9	34.4	69.4
Ratio of slope ≤ 5% and width ≤ 5m roads (%)	10.9	49.4	48.4	11.5	42.8	11	10.4	46.2	16.6

Limitations

The study focuses solely on travel routes that can be formed using the existing road system. However, when creating a travel route, various factors such as road safety, aesthetics, materials, design, etc. can also be considered in addition to the destination and road system. Plus, the number of destinations to be selected is assumed to be in the range of 4-8, considering the size of the destinations and the average number of stops on a general travel route. Beyond these assumptions, more options can be offered to the user and routes can be developed with different priorities.

Conclusion

As it is known, the Historic Peninsula has a very complex structure, and as a place that was the capital of three empires, it bears traces of quite different periods both underground and above ground. However, especially the area between Atatürk Boulevard and Topkapı (Old Eminönü), Topkapı Palace, Sultanahmet, the Grand Bazaar, the Spice Bazaar, and the Basilica Cistern are the better-known areas that first come to mind. Those who stay for 1 or 2 nights to see the city visit these areas first with official tours. However, in addition to these classical Istanbul routes, there are also very important historical and cultural routes, scenic spots, architectural examples on a single building scale, routes, and areas that reflect the original texture and past identities.

In this context, with this study, different alternatives have been explored by pointing out the points that are overshadowed by the Sultanahmet, Topkapı, and Eminönü regions but should be seen. For this exploration, generative design tools were used as decision support tools with the help of GIS. For 3 different objectives (maximizing the use of roads wider than 5 m, maximizing the use of roads narrower than 5 m, and minimizing the route length), a total of 9 alternatives were optimized with different destinations. Some of the generations have been directed in such a way that the tourist can discover other regions of the peninsula while visiting the most famous ones, while others have been directed to explore the rest of the peninsula except for the Sultanahmet-Topkapı-Eminönü regions.

For future studies, these tools can be improved through user application and can shape the routes according to the demands of the traveler and show them the ideal alternatives by using many parameters that should be taken into consideration by the decision maker. This support system can be used not only for individual use but also at the municipality scale, by determining the potential routes of tourists, focusing on these routes for a more comfortable journey, and developing special designs for these routes.

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