

Open University of Cyprus

School of Pure and Applied Sciences

Master Degree

Sustainable Energy Systems

Master Thesis



**The establishment of a pedestrian sustainable mobility index
for use in urban environments.**

Antony John Mouzas

Advisor

Asst.-Prof. Dr.-Ing. Paris A Fokaides

May 2021

Open University of Cyprus

School of Pure and Applied Sciences

Master Degree

Sustainable Energy Systems

Master Thesis

**The establishment of a pedestrian sustainable mobility index
for use in urban environments.**

Antony John Mouzas

Advisor

Dr.-Ing. Paris A Fokaides

The present dissertation was submitted for partial fulfilment of the requirements for the degree of Sustainable Energy Systems from the School of Pure and Applied Sciences of the Open University of Cyprus.

May 2021

Summary

Sustainable mobility has been considered one of the most important challenges in climate adaptation. It is responsible for a large amount of emissions and also has impacts on health, energy costs and CO₂ emissions. This pretext that the study has fought to analyse a new type of sustainability index for urban mobility. Using remote sensing data and analysis, as it is possible to grade and therefore focus investment on specific areas of the network that may exist within a study location, adding together various different types of environmental indicators as well as network quality. Using the sustainability index it is therefore possible to alleviate the issues of public investment and also provide a walkability score for pedestrians that are travelling throughout this urban space.

The methodology comprises of already existing algorithms within the QGIS environment, and are ready to be easily applicable for urban design processes. The combination of algorithms is novel and shows that there are in fact a very few areas within the chosen study location that adhere to these principles of sustainable mobility, but these available areas have been shown to be very detailed and provide a good example for this purpose.

Acknowledgements

I hereby would like to thank my Advisor, Dr.-Ing. Paris A Fokaides

Table of Contents

Chapter 1 Introduction

1.1 Abstract

1.2 Environment Setup

Chapter 2 Literature Review

2.1 Environmental Quality

2.2 Mobility

2.3 Urban Design

2.4 Vegetation Cover

Chapter 3 Materials and Methods

3.1 Study Area

3.2 Primary Network

3.3 Primary Data Sets

3.4 Serviceable Areas

3.5 Serviceable Area Overlaps

3.6 Tolerance Zone Buildings

3.7 Sustainability Index – Sampling Area

3.8 Sustainability Index – Variables

Chapter 4 Results and Discussion

4.1 Results for Sustainability Index

4.2 Area of Buildings within Sustainable Zone

4.3 Overall Score and Average Score

4.4 Lowest and Highest Scores

4.5 Shade Index of Sustainable Network

4.6 Area of Sustainable Zone

Chapter 5 Conclusion

Annex

I. Data Outputs

II. Map Views

References

Chapter 1

Introduction

1.1 Abstract

Sustainable mobility in urban environments has been considered key in the pursuit of sustainable development. Many promising initiatives have been proposed and examined but there are still very few designs that have been used that cover all cities and urban environments. There have also been very few studies that have focused on specific indicators that will allow correct decision making when designing urban spaces. The designs and indicators that have been mentioned have also focused mainly upon vehicle transportation and supply lines while pedestrian mobility has been a secondary factor in urban mobility. This study will attempt to create a model based upon the most impactful sustainability indicators when referring to pedestrian mobility, and therefore will create a sustainability index for grading the walkability of an urban environment, specifically the municipality of Nicosia in Cyprus. This study has discovered that pedestrian transportation can be graded in terms of walkability, allowing for areas of the network to be categorised and singled out in order to focus public funds into investments that will have the highest impact in terms of sustainable mobility. The study has also discovered that the use of primary electricity generation and fossil fuels for transport can be reduced if problematic areas that have a low or negative sustainability score are managed in ways that will increase the score. This will lead to a more perceivable a pleasant pedestrian mobility through urban spaces, and will encourage the exposure of commercial businesses in these walkable areas.

1.2 Environment Setup

In order to begin calculating the sustainability index, one must begin with using the latest version of pyQGIS, due to the fact that the algorithms that are being used in the calculation of this index are already part of the geospatial analysis toolbox contained within QGIS. The study area selected must have a functional network layer and the boundary to which the scope of the sustainability index will function. Along with these two layers there must also be points of interest that pedestrians are willing to visit and would constitute a rational and declared target for the pedestrian destination. In addition to this, stopping points for parking points that will act as an origin for the pedestrians to begin a theoretical journey. Gathering these aspects will allow for the sustainability index to extract the sampling areas that will be most beneficial for public investment and public funds through maintenance.

QGIS version: 3.20.2-Odense

QGIS code revision: 9f59a156

Qt version: 5.15.2

Python version: 3.9.5

GDAL version: 3.3.1

GEOS version: 3.9.1-CAPI-1.14.2

PROJ version: Rel. 8.1.1, September 1st, 2021

PDAL version: 2.3.0 (git-version: eac774)

Chapter 2

Literature Review

2.1 Environmental Quality

In any urban environment, the majority of the air pollution that exists comes from road vehicles in the form of particulate matter. Even though there are very high quality and accurate scientific equipments in order to measure the toxicology of chemical emissions or particulate matter, there is still a great difficulty in accurately measuring air pollution in any given environment. There is also a factor of air pollution deriving from exhaust and non-exhaust sources, also making it difficult to give a direct measurements for their quality further large urban sampling area unless live sensors are placed at regular intervals throughout the city, and even this would not provide the full scope on the quality of air measurements at any given time. In addition to this the type of urban area or construction may alter the measurements in any direction, such as tunnels and underground spaces (Pant and Harrison, 2013). Due to this fact and that the air quality measurements are derived from a single sensor in the city, the air quality measurements are considered constant at any given time and derive the data from the sensor.

Due to this degradation of ambient air quality due to traffic congestion and the various forms of exhaust and particular matter pollution, pedestrians face an increasing mortality rate if living near or commuting within these urban spaces. Higher volumes of traffic lead to a higher increase in emissions and therefore realised health complications due to the effects of compounds such as nitrous oxides, lead and particulate matter. This is true for both main traffic routes and side routes, as well as areas that are directly affected through the prevailing wind direction (Zhang and Batterman, 2013). For this reason the constant air quality variable that has been included in this sustainability index can be altered in a positive or negative way depending on the amount of pollution in the air at any given time, therefore leading to a positive or negative score in regards to this variable.

2.2 Mobility

Attempts at categorising urban mobility indexes has existed in the literature and has been defined as various different types of mechanised mobility including private vehicle trips, public transportation methods and routes, as well as bearing different types of network design aspects. The European commission has also issued guidance to increase the sustainability of larger cities within the European Union, but this has also been left to the various planning departments to innovate and discover methods that will work in specific use cases. The scientific literature focuses upon vehicle transportation and methods using mechanised transport, and therefore the applications of these methods have a mechanised centric design and use case. Mechanised transport is therefore very clearly defined and analysed in many case studies and is a well-known practice within the scope of mobility design (Miranda and Rodrigues da Silva, 2012; May, 2015; Moeinaddini, Asadi-Shekari and Zaly Shah, 2015).

In addition to this pedestrians have also been the focus of sustainable mobility studies, and various aspects of pedestrian mobility have been targeted and scientific methodologies have been created to cover aspects such as gap acceptance for the crossing of main streets, the issues inaccessibility with deterioration of pedestrian mobility infrastructure, and measures of attractiveness for pedestrian mobility in urban spaces. The studies have been applied in separate use cases, and are applicable in the specific areas that they have been conducted, but there are limited studies showing the interoperability of these methods and are therefore lacking in an overall approach to sustainable urban mobility when looking into urban mobility as a whole and in providing an urban mobility index that is focused on future types of mobility throughout urban spaces, including urban design aspects that will allow for establishing methods that will assist decision-makers and policymakers in the correct location and form of investment for urban infrastructure (Moura, Cambra and Gonçalves, 2011; Rismanchian, Bell and Mokhtarzadeh, 2012; Mohamad Nor *et al.*, 2017).

2.3 Urban Design

The design of urban spaces is key in order to encourage pedestrians in the built environment to choose walking as a mode of transport over other methods. There are wide-ranging benefits in pedestrians choosing walking as their method of transport such as the reduction of traffic congestion and pollution as well as a range of health benefits including obesity (Cambra, 2012). Local interventions supporting sustainable methods of transportation that encourage walking, or other methods such as public transportation and cycling have proven to improve issues of transportation and congestion in many cases throughout many urban spaces have shown to have very many positive health impacts (Giles-Corti *et al.*, 2016). In addition to this developments that may occur within the cities infrastructure, certain considerations must be taken

into account including the ecology hydrology the availability of pathing and utilities, as well as building design parks and natural areas to form an attractive whole for pedestrian accessibility and mobility to be at acceptable levels (Commission, 2009). This has been the key concept in assessing design aspects of the network area.

2.4 Vegetation Cover

Vegetation that is present within urban areas have been linked to inhabitant well-being and ecosystem services. Vegetation in private spaces as well as public spaces are key in order to mitigate the effects of climate change and to provide adequate shading for the saving of energy and also to assist with perceived temperature and air quality (De La Barrera and Henríquez, 2017). With the increasing cost of carbon and the increasing importance on ecosystem services and its cost-effective implementation, vegetation that has been used in urban areas assist in the reduction of fossil fuel use by lowering the amount of energy that is used for heating and cooling through natural processes such as shading, wind breaking and transpiration (Kovacs *et al.*, 2013). Although trees have been shown to be a method of choice for the implementation of nature-based solutions in urban areas, and is used to reduce the effects of heat islands in large cities, there is a stark difference between the types of vegetation and their overall effect on the environmental indicators seen in this paper. Although these are normally not considered metrics in public planning, they are often not considered and generalisations occur. There is an importance in the balance between the ecosystem services the vegetation provides and also the costs of maintenance and the damage caused to infrastructure by growing trees (Wang and Akbari, 2016; Vieira *et al.*, 2018).

Chapter 3

Materials and Methods

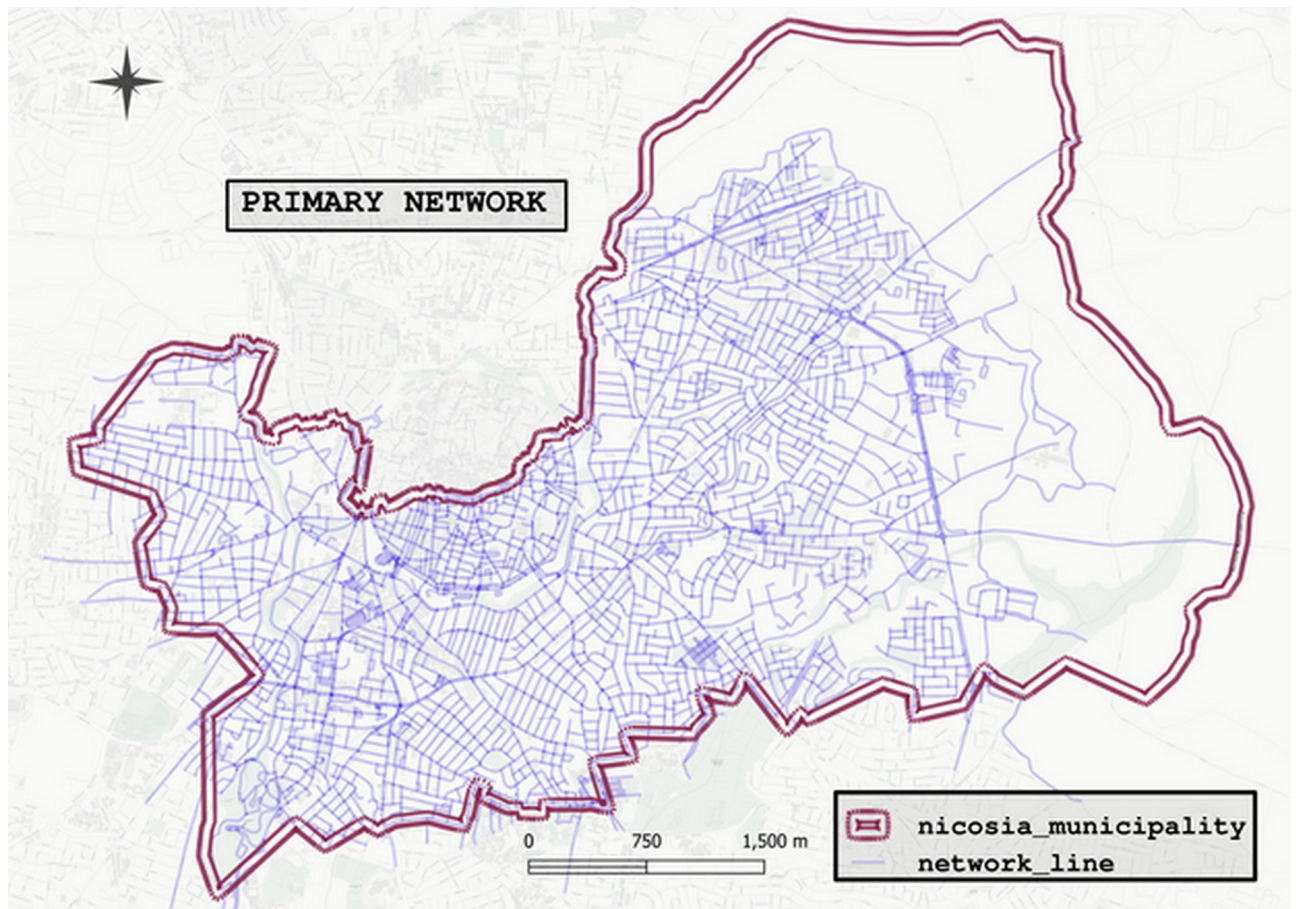
3.1 Study Area

In this method section will be going through the various steps in order to achieve the sustainability index score for pedestrian accessible networks. These will be illustrated via map views with descriptions that dictate the process.



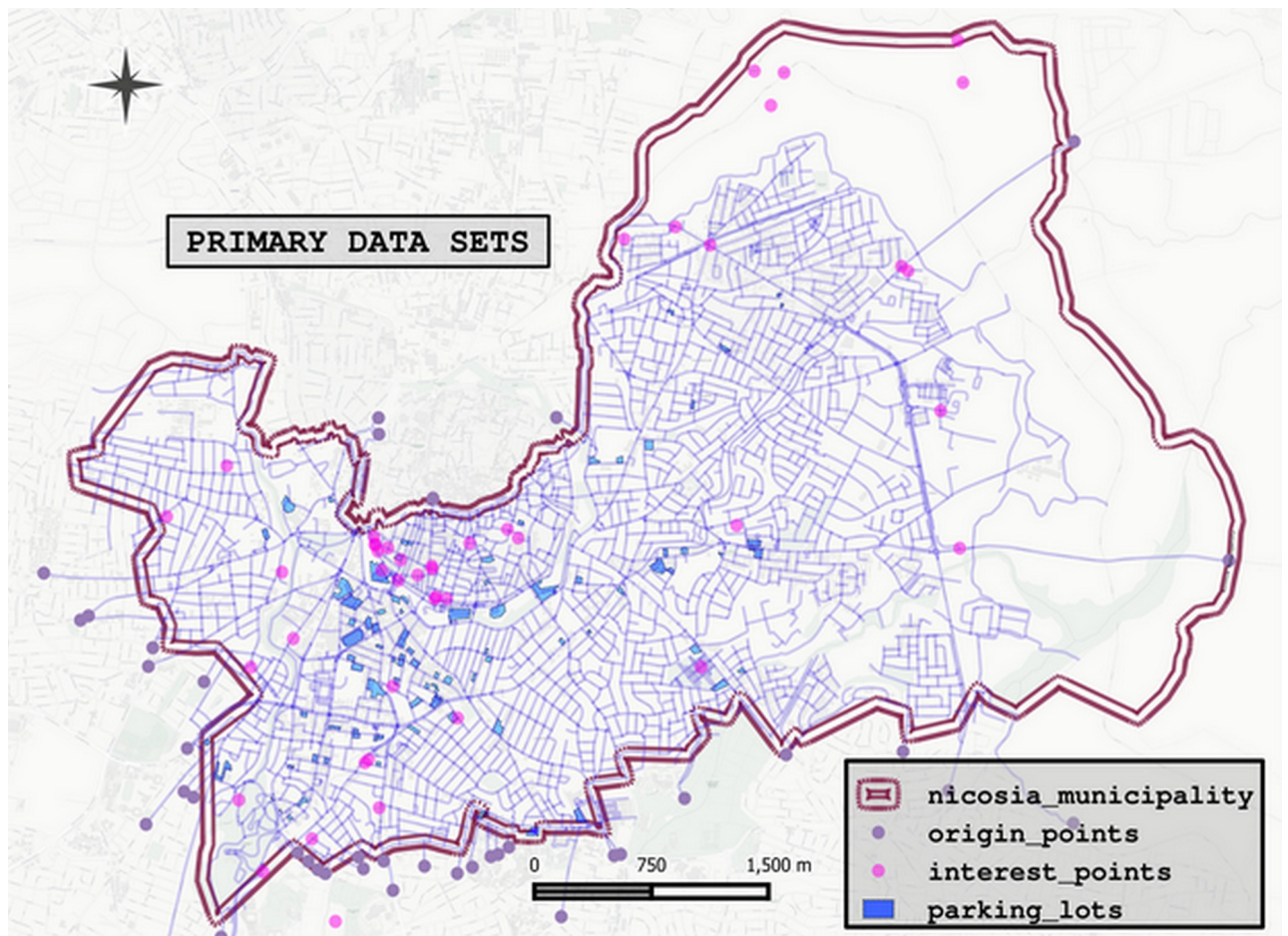
In this map view we have the study area this shape file depicts the unoccupied area of Nicosia. Archived satellite imagery was analysed and the highest quality satellite imagery of the Nicosia municipality (Google Earth Engine) was digitized, rasterized in order for geospatial analysis. Building aspect and shading, vegetation as well as network were digitized from this imagery. The network was digitised by hand placing the vertices precisely in the centre of dual lane roads, allowing for attributes such as one way and dual carriageway. These were ignored in the calculation of sustainability index due to the fact that the method of transportation is pedestrian mobility and not motor vehicle mobility. The buildings that were digitised were solely within the acceptable areas, in order to save resources. The vegetation that was digitised was conducted using freehand digitisation due to the sporadic and low density of vegetation within the municipality. The municipality boundaries were digitised using official government records in order to ensure accuracy.

3.2 Primary Network



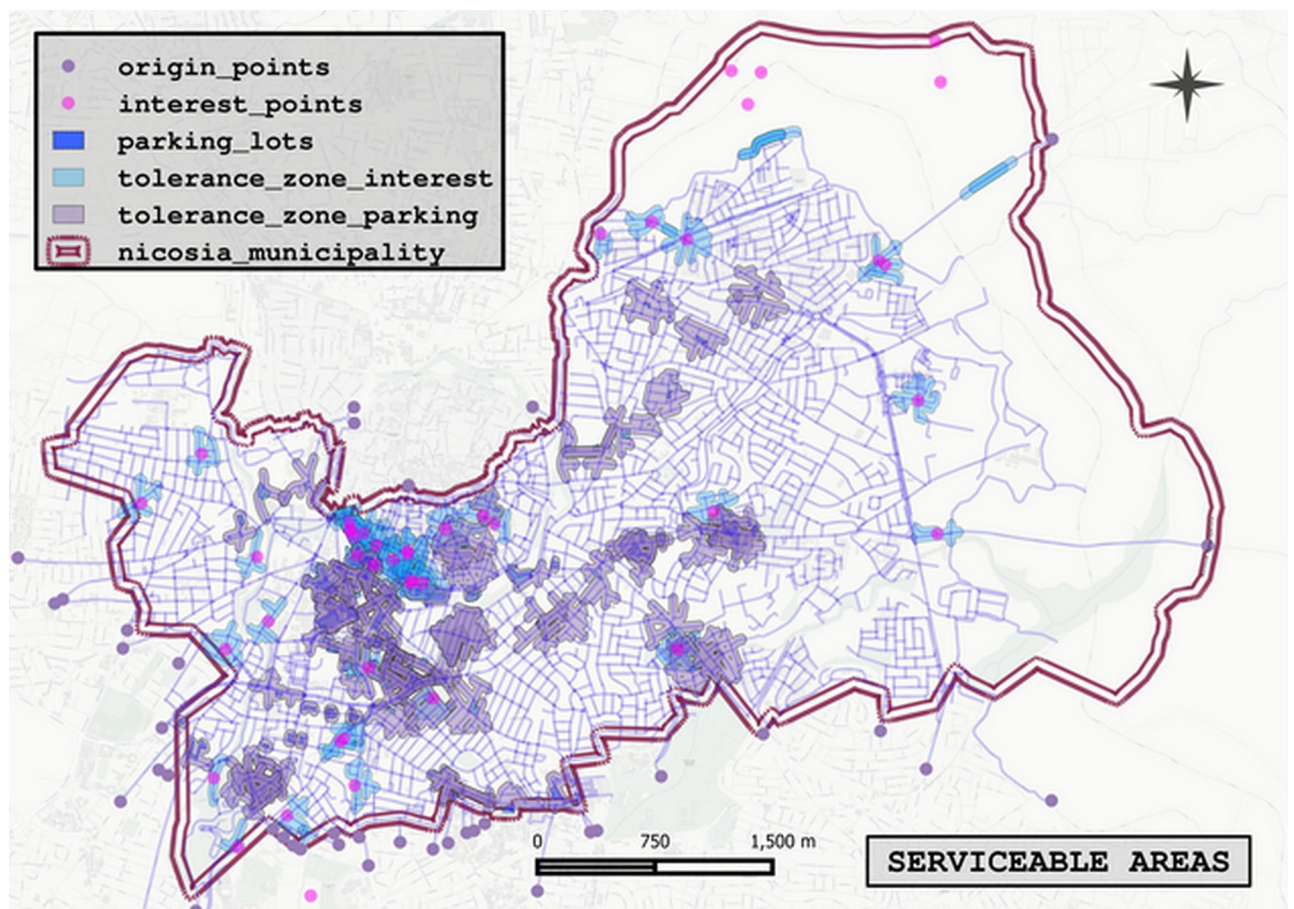
Here we can see the digitized network in the entire municipality. On the initial analysis of this network there were aspects that were inaccurate for our purposes and had to be simplified. Also there were network lines that were incomplete and had to be adjusted in order to reflect reality. We can also see that there are points in the network that radiate out from the boundaries of the municipality and therefore these were considered origin points for our purposes. These are two points were used in a theoretical manner to allow for vehicle transportation to parking points, and pedestrian mobility would be used from these parking points to areas of interest. The alterations made to the network include pedestrian walkways that are inaccessible to motor vehicle transport, the formation of a network within parking lot spaces in order to allow for coded and theoretical vehicles to find parking spaces within these parking lots, and some tracks within certain buildings that are commonly used by pedestrians for mobility access. The alterations did not include pathing through land use structures such as fields and parks due to the possibilities of pathing being too many for efficient processing power and would limit the possibilities for calculation as well as the computation time. After the preparation of this network layer, points of origin as well as points of interest for pedestrians were taken from already existing map data either from open source or from a pool of important buildings and services most likely to be used by pedestrian access. These again were limited to a certain amount due to the efficiency of computational power when creating random models. The points of origin are a discrete number and cannot change.

3.3 Primary Data Sets



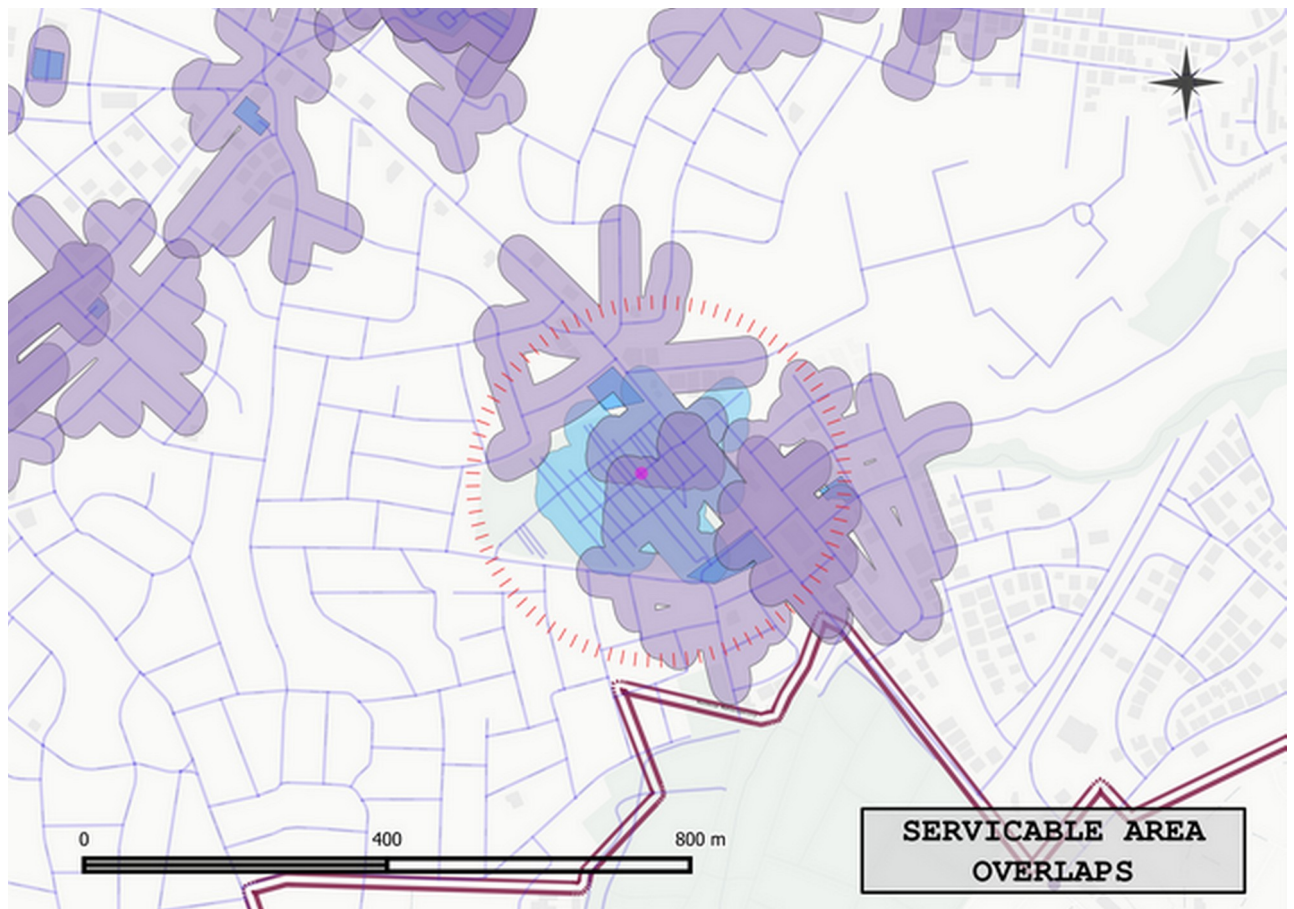
In this map view we can see the marked origin points mentioned in the previous figure. These data points were coupled with various interest points that we have in the municipality, as well as the various parking lots that visitors use for disembarking into the city. These three points created the foundation for our analysis, by using the serviceable area of both the parking lots and the interest points. In this map you we can clearly see the concentration of interest areas in pink, which seem to be focused closely around the city centre and specifically within the walled areas of the municipality. The origin points in purple have all been placed just outside the boundary of the Nicosia municipality, to simulate incoming and outgoing traffic from the area of the municipality. The highest concentration of entry points into the municipality are in the south and the west of the outermost boundary, due to the North and East orders of the municipality being occupied by Turkish forces since 1974. The origin points also show the realistic aspect experienced by traffic goers within the municipality, as these origin points experienced the highest amount of vehicle traffic. The parking lots depicted in blue can be seen to be highly concentrated in the city centre alongside the interest points, but can also be seen spread throughout the municipality, closely following main roads and high traffic areas. The amount of available space within these parking lots as well as the accessible parking lots for disabled vehicles and pedestrians has been clearly defined and can therefore be used in high accuracy simulations and models to assist with decision and policy making on sustainable mobility in the municipality.

3.4 Serviceable Areas



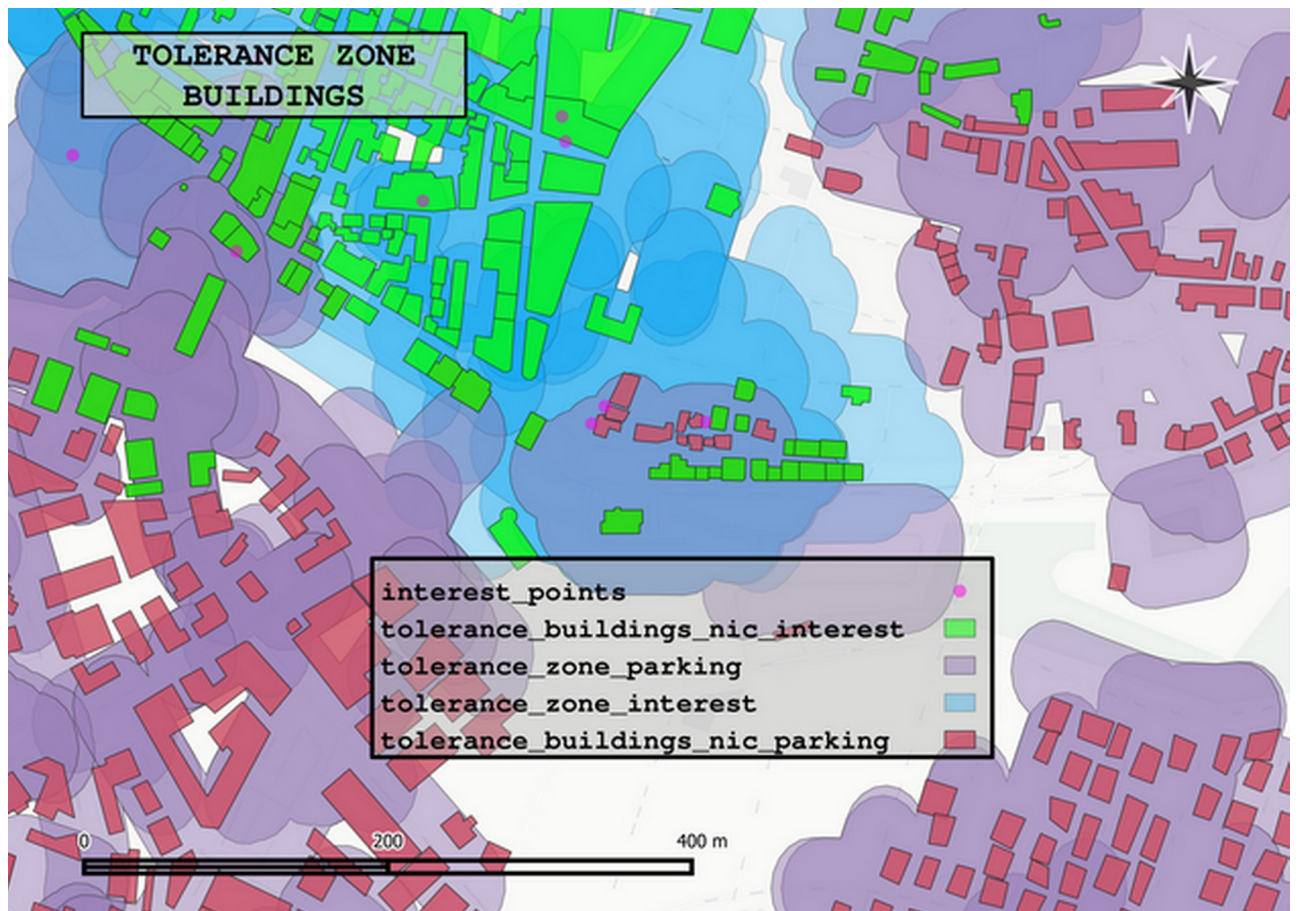
Here are the total serviceable areas around each interest and parking point, creating a tolerance zone to which pedestrians are able to reach within five minutes at an average speed of 3 km/h. This led to the theory that traffic that travels into the municipality uses these parking spaces to disembark from their vehicles in order to walk to various interest points that exist within the municipality. This also creates an overlapping area to which we can consider as more sustainable. These areas have been created by using the serviceable area algorithm provided by the qgis platform, and creating a buffer around the serviceable areas in order to incorporate infrastructure such as buildings, parking lots and interest points. The serviceable areas in purple are the serviceable areas around the existing parking lots in the municipality. These can be seen to be a lot more than the serviceable areas around the interest points in the municipality, which are shown in blue. The serviceable areas for parking lots are only considered for publicly accessible parking lots, and do not include private parking facilities or parking facilities that are associated with residences within the municipality. The serviceable area for interest points does not include areas of commerce or commercial areas, but rather official buildings, museums, historical landmarks and official offices. As a lot of these areas do not overlap, these will not be considered as sustainable for our purposes, due to the amount of time and distance that it would take for a pedestrian to access these areas, and therefore is considered out of scope in order to receive a score for sustainability. The areas that are considered for sustainability index are only those that fulfil distance and time criteria from parking lots amenities to points of interest.

3.5 Serviceable Area Overlaps



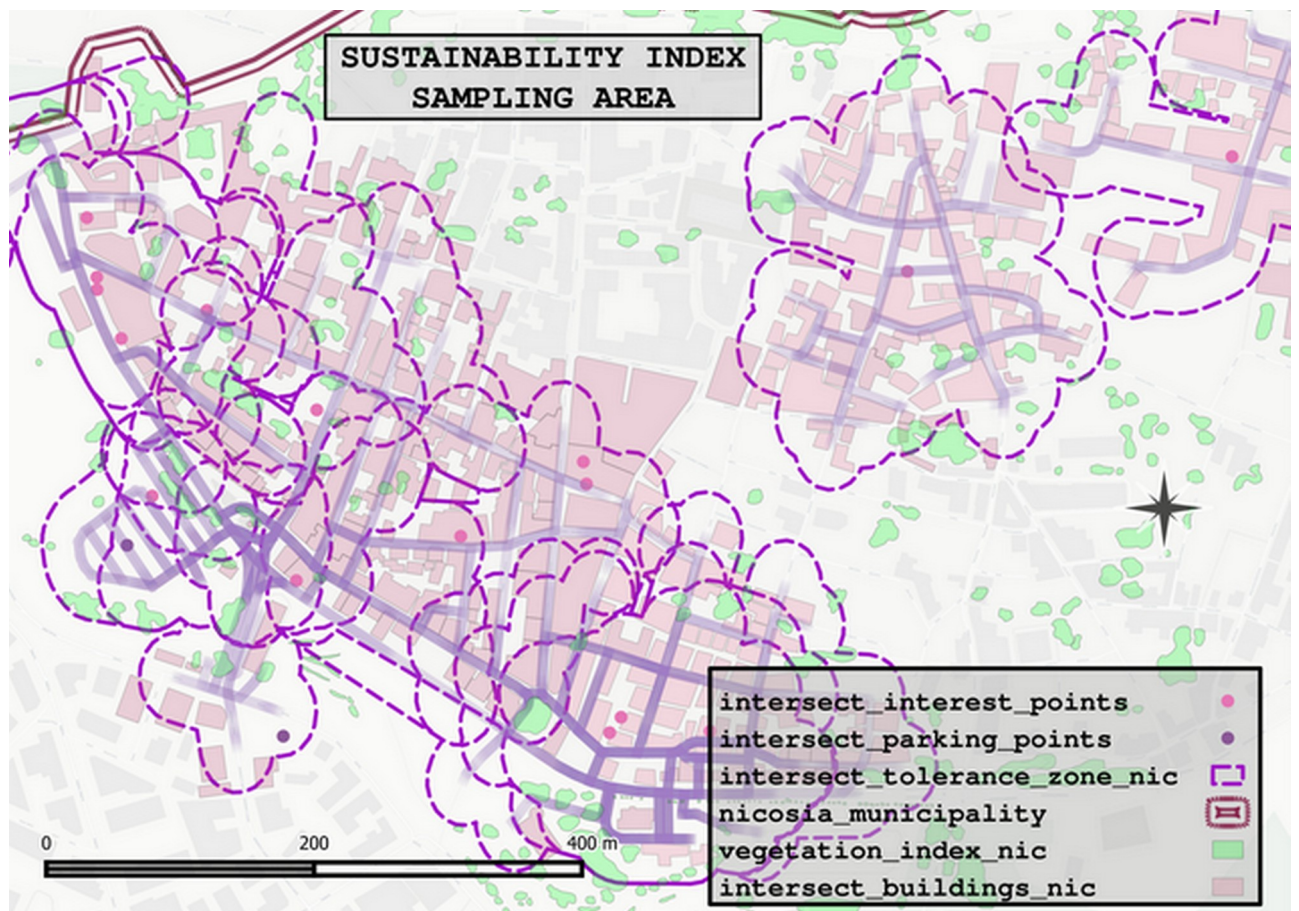
This is a view of the before mentioned overlapping areas in the algorithm, delineated by the red circular shape file, and as we can see there is an interest point directly adjacent to two parking points and the areas that are in purple are the network areas that are within the serviceable distance of the parking lot and the lighter blue areas are the serviceable distance within a cemetery, in this case our interest point. It is important to only incorporate overlapping areas due to the fulfilment of the distance and time criteria for pedestrian mobility. It is also important to understand that the more overlapping areas that exist within a study area, the more sustainable mobility aspects can be observed. It is also important to understand that some areas that are in the serviceable areas of the interest points have unique characteristics, much like the map view above. In this case the entirety of the serviceable area within this interest point is in fact the grounds of a very large cemetery, with a multitude of pathways and trees for shading. The parking lots that are both on the north and south side of this interest point area, are in fact parking lots that are used in order to service this cemetery, and therefore the serviceable areas of these parking lots overlap with the serviceable area of the interest point and allow for the surrounding buildings to become more sustainable.

3.6 Tolerance Zone Buildings



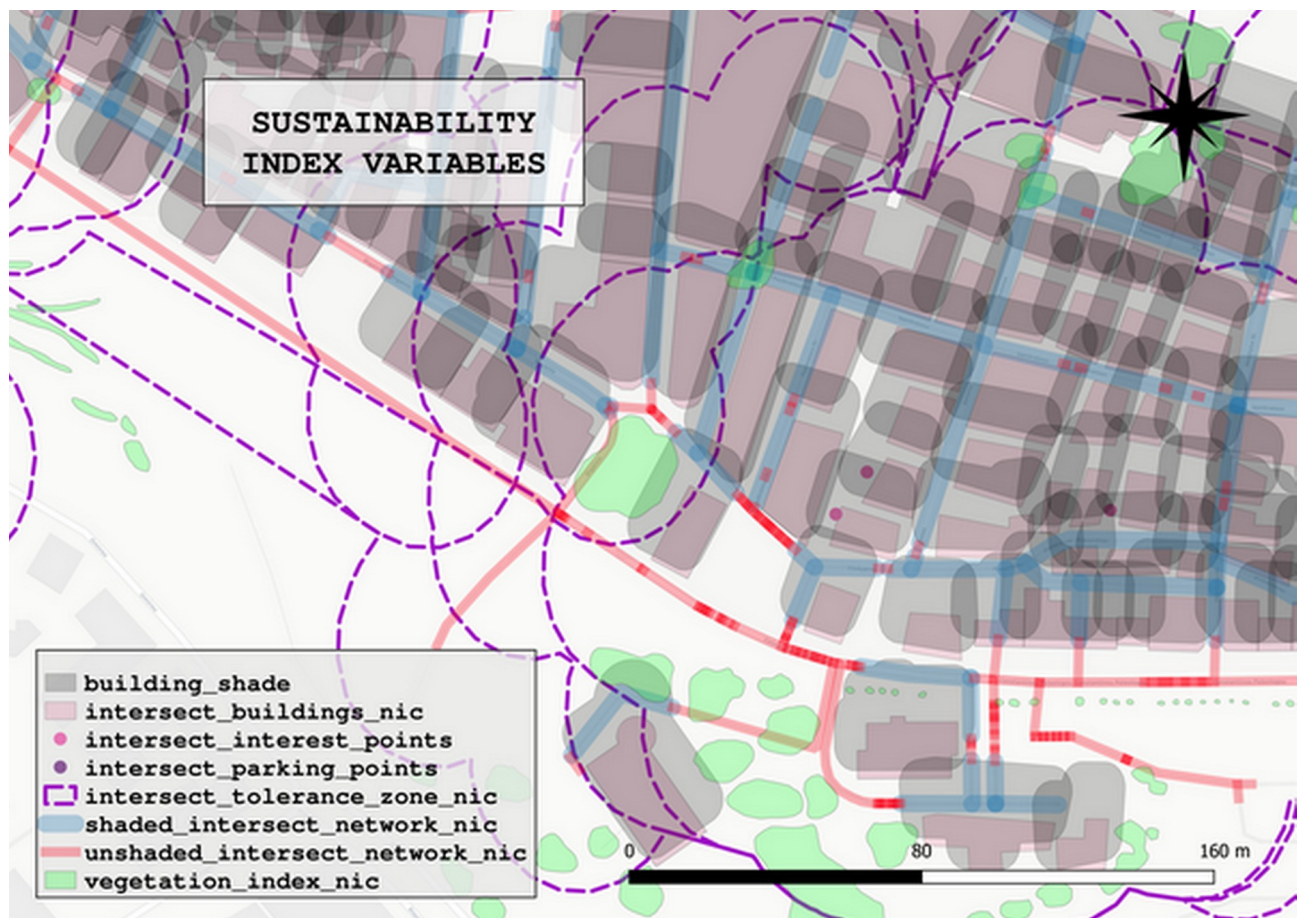
In order to derive the correct aspects of shading and for what area, there was a digitisation of the existing buildings in the satellite imagery that were within these two tolerance zones. The buildings that have been digitised here can be considered sustainable due to their close proximity to the interest points and the parking points. The overlapping buildings were gathered in order to create a database for highly sustainable buildings. Buildings that did not overlap in this manner were disregarded due to them not being within the acceptable distance required for this index, and therefore were out of the scope of the sampling area. These buildings can be placed in individual groups, being that of the tolerance zone of either parking points for interest points, but buildings that are located within the intersect of these zones are buildings that can be targeted for sustainable development and are of key interest for this index. Pedestrians would be exposed to these buildings due to their location and would be beneficial for policymakers and developers to invest in either residential or commercial aspects of these buildings.

3.7 Sustainability Index – Sampling Area



These before mentioned details have led to the conclusion that there is a sampling area that meets the requirements for sustainable mobility in the municipality of Nicosia. These are at the confluence of the networks that join interest points with facilities for private and public motor vehicle parking. The areas in purple are the intersects of these two areas showing the exact size of the network with the adjacent buildings and vegetation cover can be seen in green. The intersect network area was then split into smaller fractions in order to determine the following components of the sustainability index, which is the shade index. Each fraction was then provided with a score depending on the value of the indicators present. The details of all available shape file layers was extracted based on the sampling area labelled as the intersect of the tolerance zone, and therefore only these aspects were considered in this study due to the remainder of the data points falling outside the scope of this sampling area and therefore considered to be unsustainable.

3.8 Sustainability Index – Variables

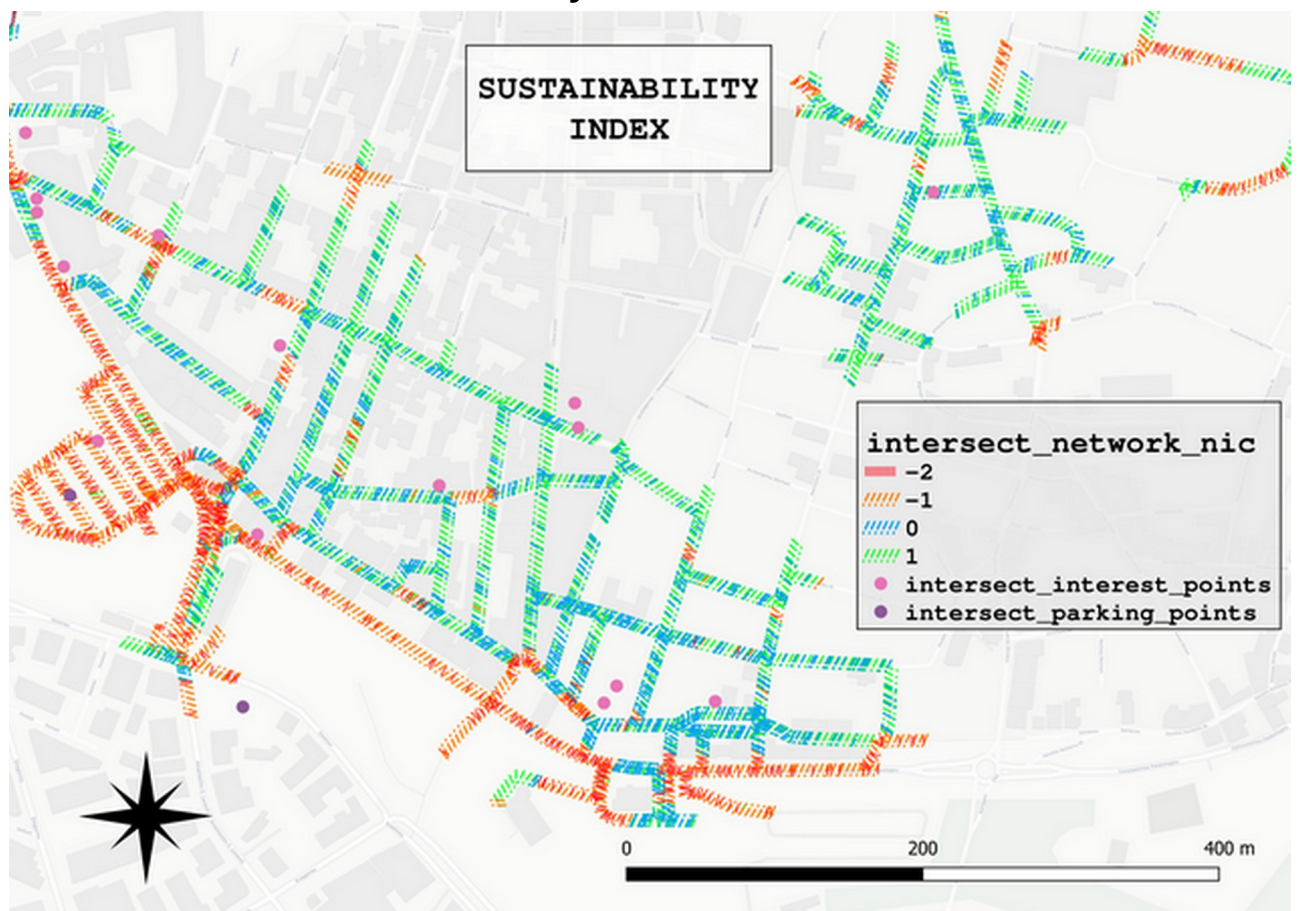


After the sampling area has been gathered using the methodology mentioned above, aspects of shading of the buildings were given an average value in order to reflect a 2 1/2 floor building. Buildings that were quite tall were adjusted to reflect the taller building aspects and the shading that was cast upon the ground. Due to the fact that air quality is generally constant, and temperature although fluctuating is constant at any given time, and also given that the climate of Cyprus is generally hot rather than cold, areas of the network that were in full sunlight were given a negative score and areas of the network that were in complete shade were given a positive score. As we can see in the map view above, the network score has already begun to take shape as the various segments of the network have been split into sustainable and unsustainable scores. The overlap function available within the qgis infrastructure was used with the shape file labelled building shade, and the random point sampler function available within qgis, was used in order to determine a certain percentage of obstacles within the network, in this case the obstacle level was set at 10% of the available network. Obstacles that have been included in the obstacle types are events such as cars parked on pavements, obstructing items and infrastructure, as well as poor pavements quality or inadequate paving size.

Chapter 4

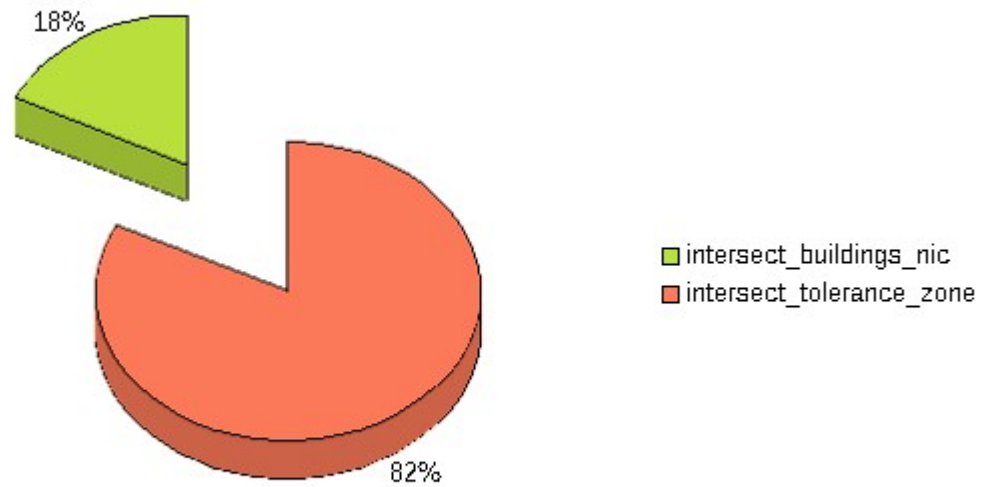
Results and Discussion

4.1 Results for Sustainability Index



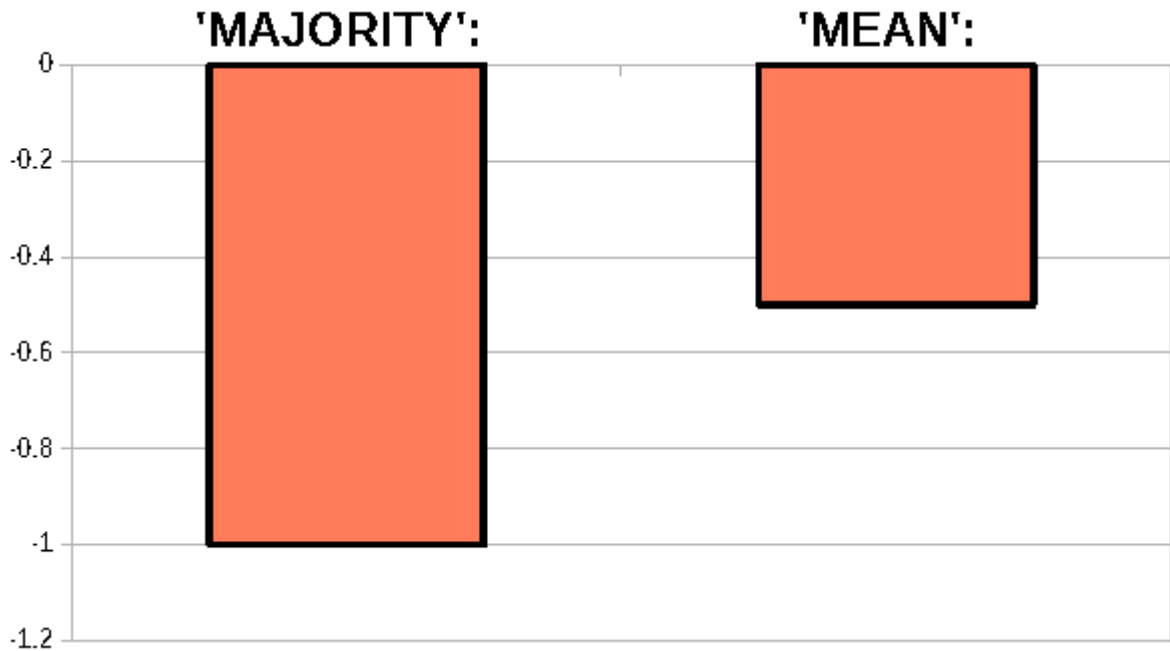
And therefore in this map you we have the sustainability index of the Nicosia municipality. This map can be updated daily with temperature and air quality data, which would affect the score of the network walkability. Also on this index, due to the various different obstacles that can be found whilst navigating these areas as a pedestrian, can be seen through the short spans of negative score network within the positive score networks that would essentially be acceptable in any other form of variable. The lines in red are a very cautionary -2 on the score. This means that they are exposed and offered little to no walkability and therefore do not offer a sustainable method of pedestrian mobility, while the areas in blue and green have a higher score and in fact a positive score means that it is a pleasant and short distance experience for pedestrians as well as being near the points of interest that the pedestrians desire to walk to.

4.2 Area of Buildings within Sustainable Zone



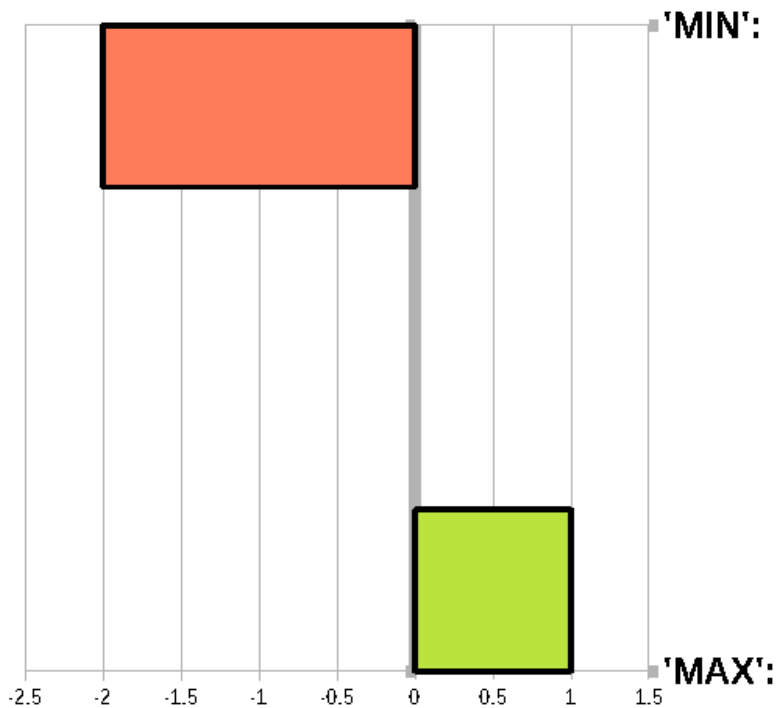
In this diagram we can see that the total area of the tolerance zone and the area of the buildings that are considered sustainable within this tolerance zone. We can see that 18% of the total area within the acceptable distance for pedestrians contain buildings that can be used for all purposes either residential or commercial. The other 82% of this area is considered walkable area, and includes network, paving, buildings and green areas. This is of specific interest to policymakers and urban design officials due to the fact that there is a visible issue regarding pedestrian accessibility within the city, also that there is a considerable room for investment regarding the placement of interest points within the municipality and also the inadequacy of available parking spaces for both commuters and visitors that require access to place their vehicles. It is important for policymakers and urban design officials to consider alleviating some of the present issues in regards to infrastructure placement and availability within the municipality. It is also important to note that the remaining area of the municipality does not even reach the minimum standards of sampling that is present in this index, and the criteria for this index is very lenient regarding the distance that pedestrians are willing to travel within an unsustainable environment.

4.3 Overall Score and Average Score



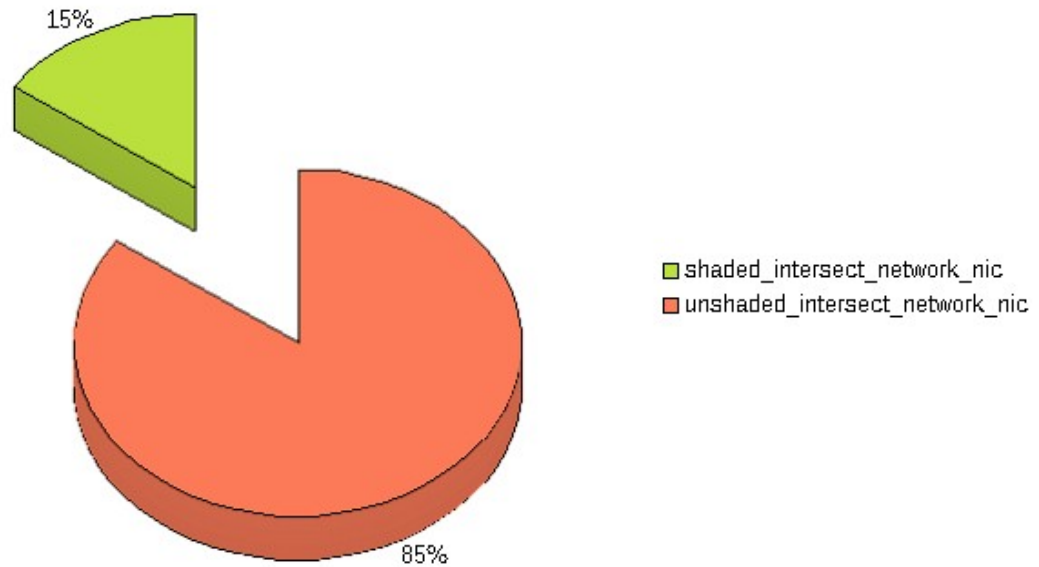
In this diagram we can see that the majority of the network walkability scores are at -1, which means that of the sustainable network area, the majority has a negative score. This is also depicted in the mean value which is at -0.5, which means that although there are some positive scores along the network, the average value is still negative. This is important information for policymakers and urban design officials due to the fact that the available network that is within the sustainable sampling area, is overall at a negative value which implies that there is a serious issue regarding the mobility of pedestrians within the municipality. Pedestrians unwillingness to access the municipality's network via pedestrian trafficking is evident in the traffic issues, parking issues and congestion issues that are visible in the municipality on a daily basis. It is also important to note that if the sustainable network area has a negative mean score, there is a considerable issue in regards to the design of this network for the accessibility of pedestrians. This could possibly be due to the limited amount of shading, the various obstructions that can be found while pedestrians are mobilising, and the attractiveness of infrastructure such as paving.

4.4 Lowest and Highest Scores



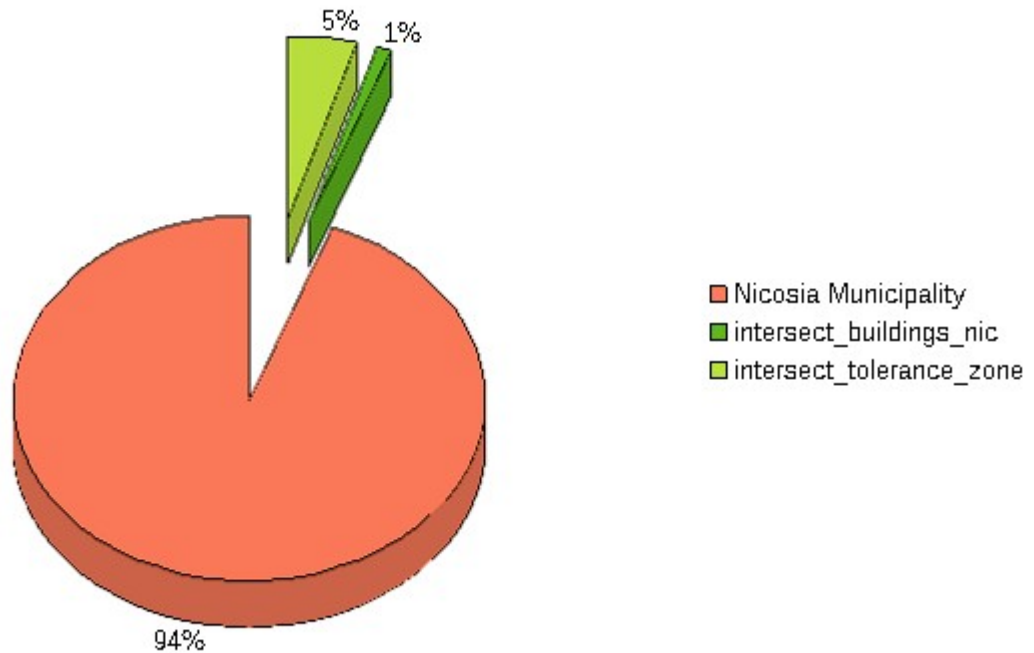
In this diagram we can see the minimum and maximum values in regards to sustainability score, with a maximum value of this is at 1, and the minimum is at -2. This means that the worst conditions that can be found within the network area are at the level of -2, which is the lowest score possible. While in good examples of the network area the maximum level of 1 is found and the maximum score available for the network is 2. The areas of the network that can be found with the highest score can be witnessed in the full sustainability index map, and these are shown to be areas with high vegetation coverage, shading and inadequate paving along with short distances from parking infrastructure to areas of interest. This can be seen in the interior of the walled part of the city, as well as two points outside the wall the areas being the route from a park towards its parking infrastructure and the cemetery mentioned in the map view above. The minimum score can be witnessed along the newly developed pedestrianised paved area along the walls of old Nicosia, due to the amount of exposure that the pedestrians have to endure via the lack of shading, even though this is in close proximity to the largest public transport hub in the municipality, being Solomou square, and very large aboveground and underground parking parking structures. It is also important to note that the specific areas are some of the closest to a large cluster of interest points that exist within the walled city, and it is important to note that there must be an alleviation regarding the negative score persists in these parts of the network.

4.5 Shade Index of Sustainable Network



This diagram can see the percentage of shaded network available for pedestrians, which is at 15% of the total network area, as well as the amount of unshaded network area, which is at 85%. This means that of the entire sustainable network area only 15% is considered acceptable regarding shading. This is important for policymakers and urban design officials to consider in a high-temperature environment such as is found in the centre of cities and especially on the island of Cyprus. If 85% of the sustainable network is unshaded, this means that there is an incredible lack of shading that exists within the municipality of Nicosia and this would have adverse effects on the ability of pedestrians to fully utilise the network system. There must be an alternative solution to the shading issue that exists within the municipality. The 15% that is shaded has found to be within heavily vegetated areas and also in the inner walls of the city, where the buildings are in very close proximity to the other, and street widths are quite low. It is therefore important for policymakers and urban design officials to incorporate new design aspects into the inner city area to alleviate this issue. If this issue is resolved more sustainable walkability scores will be observed within the municipality.

4.6 Area of Sustainable Zone



In this diagram we can see the total area of the Nicosia municipality which is not sustainable, this is 94% of the total area. While the total area of sustainable buildings and acceptable distance zones within the municipality add up to 1% and 5% respectively. This means that of the total area available for land use within the Nicosia municipality, only 6% of this total area is of an acceptable sustainability value in geospatial terms, keeping in mind that of the 6%, the majority is of a negative sustainability value. It is important for policymakers and urban design officials to single out the buildings noted within this study and provide similar examples of proximity for pedestrians to be able to access this infrastructure, and also for private entities and owners to utilise these in a more sustainable manner. The encouragement of business and private owners in these buildings will have a more valuable property if amenities, utilities and necessary businesses, as well as popular businesses are found within close proximity of their dwelling. This is also the case for places of employment, and a vital proponent to this method of inner-city vehicle congestion, as place of employment must be located nearer to places of work.

Chapter 5

Conclusion

Noticing the various map views that can be found in annex two, we can see the remainder of the sustainable areas in their entirety. These are in fact the findings of the sustainability index and clearly define obstacles as well as interest points along with their respective scores for the accessible network. It is evident that paving structures that orientated themselves east to west have a higher difficulty maintaining their sustainability index. It is also noted that the vegetation does not necessarily improve the score of the network. It is also noted that obstructions in key junction areas seem to cause the highest impact in negative score. We can also see that there may be negative score is outside and around interest and parking points, which are arguably some of the most important points in the sustainability areas. We can also see that areas that are very heavily vegetated can assist with the score if the shaded areas are of an adequate height to cover different aspects of paving. It is also important is to note the lowest scoring network lengths adjacent to parking points, which clearly shows that vehicle temperatures are at their highest in these areas.

Integration of the sustainability index is key in order to address some of the larger issues in urban design and pedestrian mobility. It is imperative that the database that has been accumulated with this study be improved upon and the data points increased in order to gain further accuracy in the map details. The expansion of these areas by including interest points closer to areas and infrastructure that can be accessed by parking is important to achieve sustainability goals in terms of mobility. It is important to accumulate large forms of shade bearing vegetation in order to offset carbon emissions and to mitigate the effects of the urban heat island. The provision of accessible paving and infrastructure is crucial to help increase the score of sustainable networks. The best scoring areas have always been places where parking and interest points were in close proximity and had adequate shading either through correctly place vegetation or structures, confined with a north to south facing direction.

Therefore in conclusion of this study we can see that building placements, vegetation placement, paving quality, parking amenity and places of interest have a key role to play in meeting urban design criteria for sustainability using this index. This study can be implemented in any urban environment and can assist policymakers and urban design officials to focus investments and design resources into these areas, which allows for a new type of metric when considering urban infrastructure, urban expansion and mitigation of environmental impact. Further research into this area can provide with more accurate results for the creation of a standard model which can be used in the process of urban network development.

Annex

I. Data Outputs

I.1 Statistics for the Area of Nicosia Municipality

Input parameters:

```
{ 'FIELD_NAME' : 'AREA',  
'INPUT_LAYER':Nicosia Municipality.gpkg|  
layername=Nicosia Municipality}
```

Results:

```
{'COUNT': 1,  
'SUM': 20697784.4692015,  
'UNIQUE': 1}
```

I.2 Statistics on the sustainability score of the sustainable network

Input parameters:

```
{ 'FIELD_NAME' : 'SCORE',  
'INPUT_LAYER':intersect_network_nic.shp|  
layername=intersect_network_nic}
```

Results:

```
{'COUNT': 10,  
'CV': -2.23606797749979,  
'FIRSTQUARTILE': -1.0,  
'IQR': 2.0,  
'MAJORITY': -1.0,  
'MAX': 1.0,  
'MEAN': -0.5,  
'MEDIAN': -1.0,  
'MIN': -2.0,  
'MINORITY': 0.0,  
'RANGE': 3.0,  
'STD_DEV': 1.118033988749895,  
'SUM': -5.0,  
'THIRDQUARTILE': 1.0}
```

I.3 Statistics on the area of sustainable buildings for pedestrians.

Input parameters:

```
{ 'FIELD_NAME': 'AREA',  
'INPUT_LAYER':intersect_buildings_nic.shp|  
layername=intersect_buildings_nic}
```

Results:

```
{'COUNT': 597,  
'CV': 1.2357273170660852,  
'FIRSTQUARTILE': 166.0,  
'IQR': 247.0,  
'MAJORITY': 109.0,  
'MAX': 5172.0,  
'MEAN': 366.7185929648241,  
'MEDIAN': 265.0,  
'MIN': 16.0,  
'MINORITY': 16.0,  
'RANGE': 5156.0,  
'STD_DEV': 453.1641830026718,  
'SUM': 218931.0,  
'THIRDQUARTILE': 413.0,  
'UNIQUE': 397}
```

I.4 Statistics on the length of sustainable network for pedestrians

Input parameters:

```
{ 'FIELD_NAME' : 'length',  
'INPUT_LAYER':intersect_network_nic.shp|  
layername=intersect_network_nic}
```

Results:

```
{'COUNT': 10,  
'CV': 1.6954486874627013,  
'FIRSTQUARTILE': 7.123246667933614,  
'IQR': 2178.4292671381127,  
'MAJORITY': 5.629976104829534,  
'MAX': 10138.272573054393,  
'MEAN': 1857.8796347186403,  
'MEDIAN': 60.60255692467208,  
'MIN': 5.629976104829534,  
'MINORITY': 5.629976104829534,  
'RANGE': 10132.642596949563,  
'STD_DEV': 3149.9395881474015,  
'SUM': 18578.796347186402,  
'THIRDQUARTILE': 2185.552513806046,  
'UNIQUE': 10}
```

I.5 Statistics on the shaded length of the sustainable network

Input parameters:

```
{ 'FIELD_NAME': 'length',  
shaded_intersect_network_nic.shp |  
layername=shaded_intersect_network_nic}
```

Results:

```
{ 'COUNT': 1,  
  'SUM': 2.937590253932452,  
  'UNIQUE': 1}
```

I.6 Statistics on the length of unshaded sustainable network.

Input parameters:

```
{ 'FIELD_NAME': 'length',  
'INPUT_LAYER': 'unshaded_intersect_network_nic.shp|  
layername=unshaded_intersect_network_nic}
```

Results:

```
{ 'COUNT': 1,  
'SUM': 16.560948810771738,  
'UNIQUE': 1}
```

I.7 Statistics on the area of acceptable networks for pedestrians.

Input parameters:

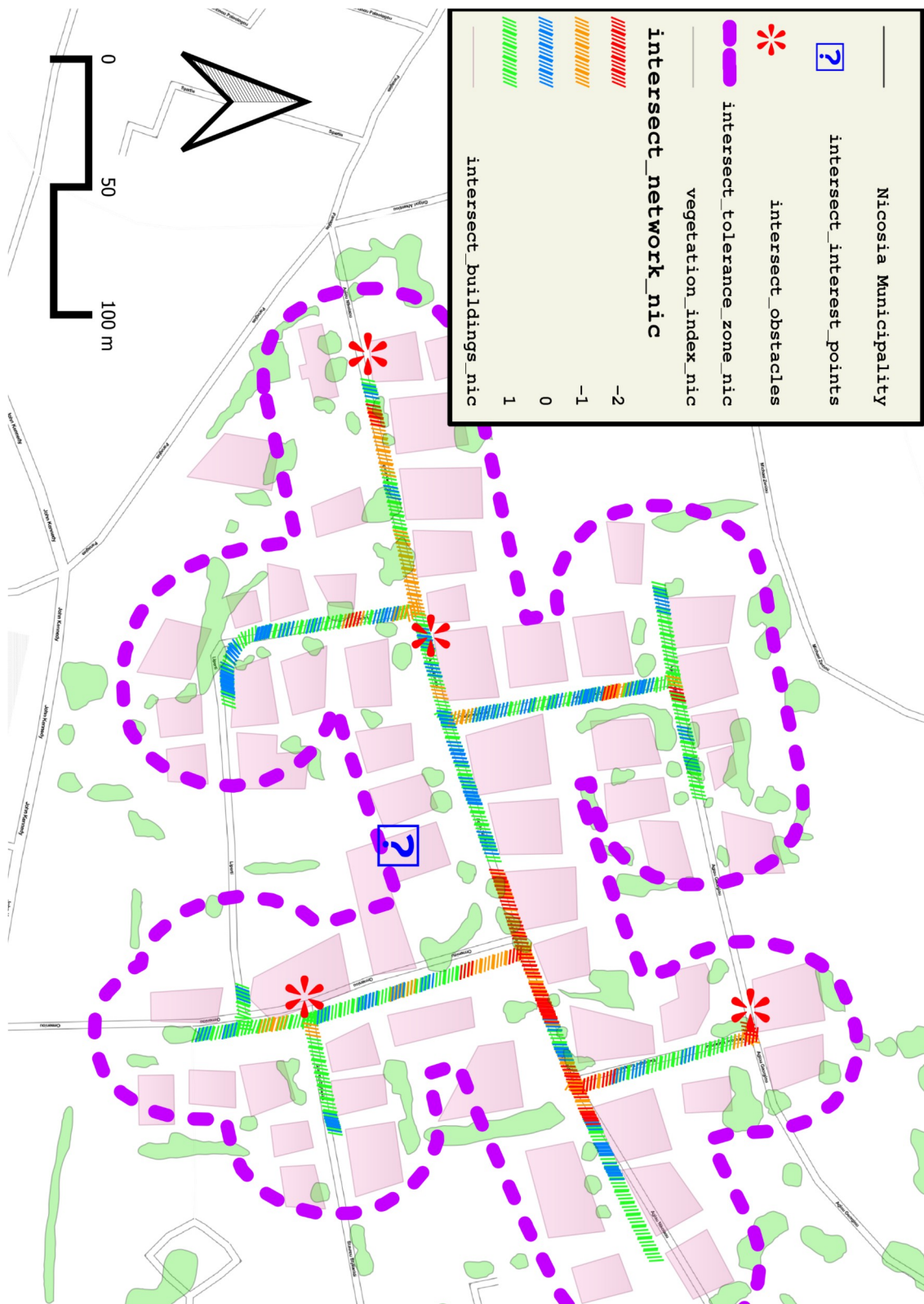
```
{'FIELD_NAME': 'AREA',  
'INPUT_LAYER': intersect_tolerance_zone_nic.shp|  
layername=intersect_tolerance_zone_nic}
```

Results:

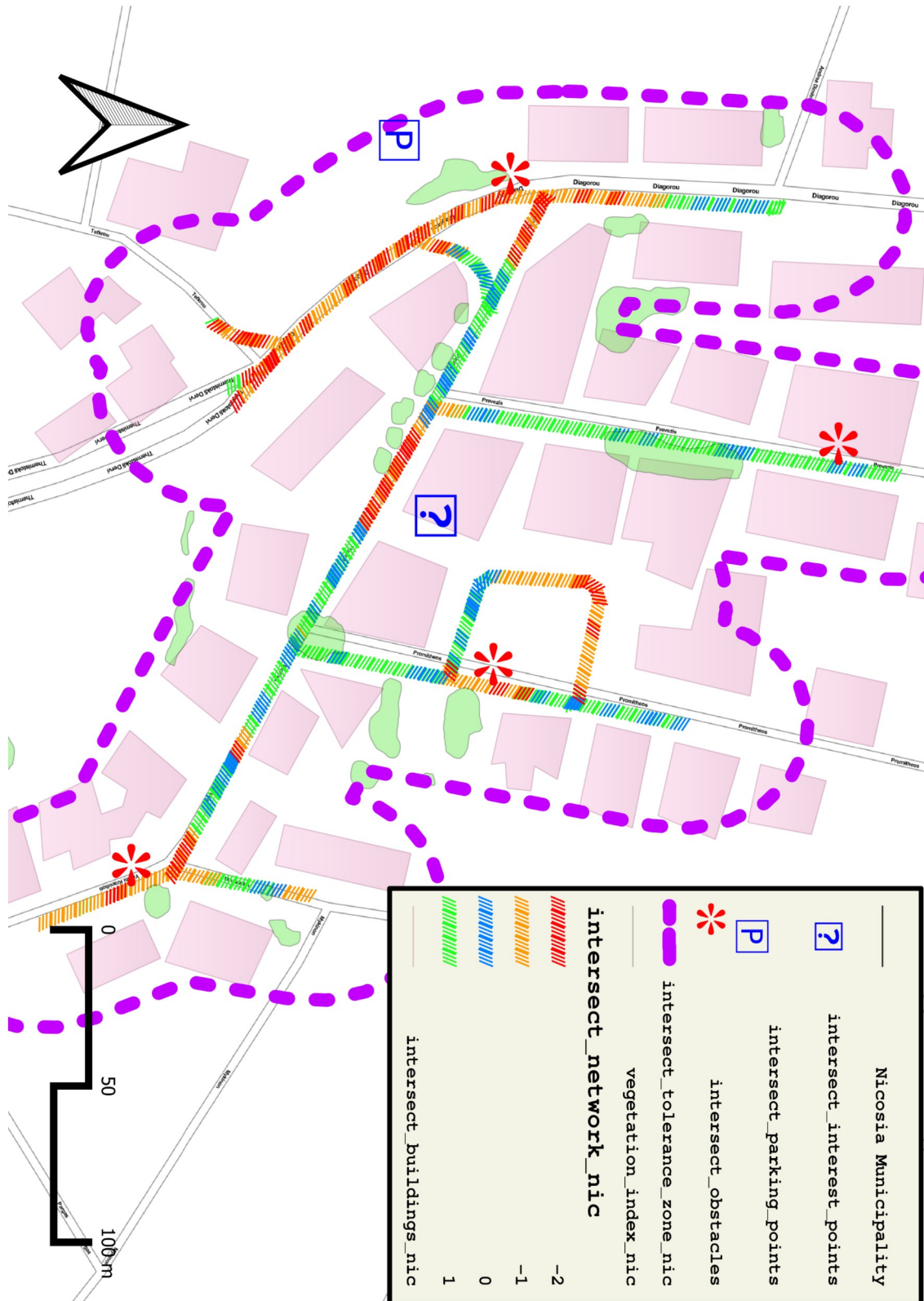
```
{'COUNT': 23,  
'CV': 0.28432618993877723,  
'FIRSTQUARTILE': 39822.0,  
'IQR': 16379.5,  
'MAJORITY': 16585.0,  
'MAX': 62742.0,  
'MEAN': 44779.434782608696,  
'MEDIAN': 44226.0,  
'MIN': 16585.0,  
'MINORITY': 16585.0,  
'RANGE': 46157.0,  
'STD_DEV': 12731.966079351087,  
'SUM': 1029927.0,  
'THIRDQUARTILE': 56201.5,  
'UNIQUE': 23}
```

II. Map Views

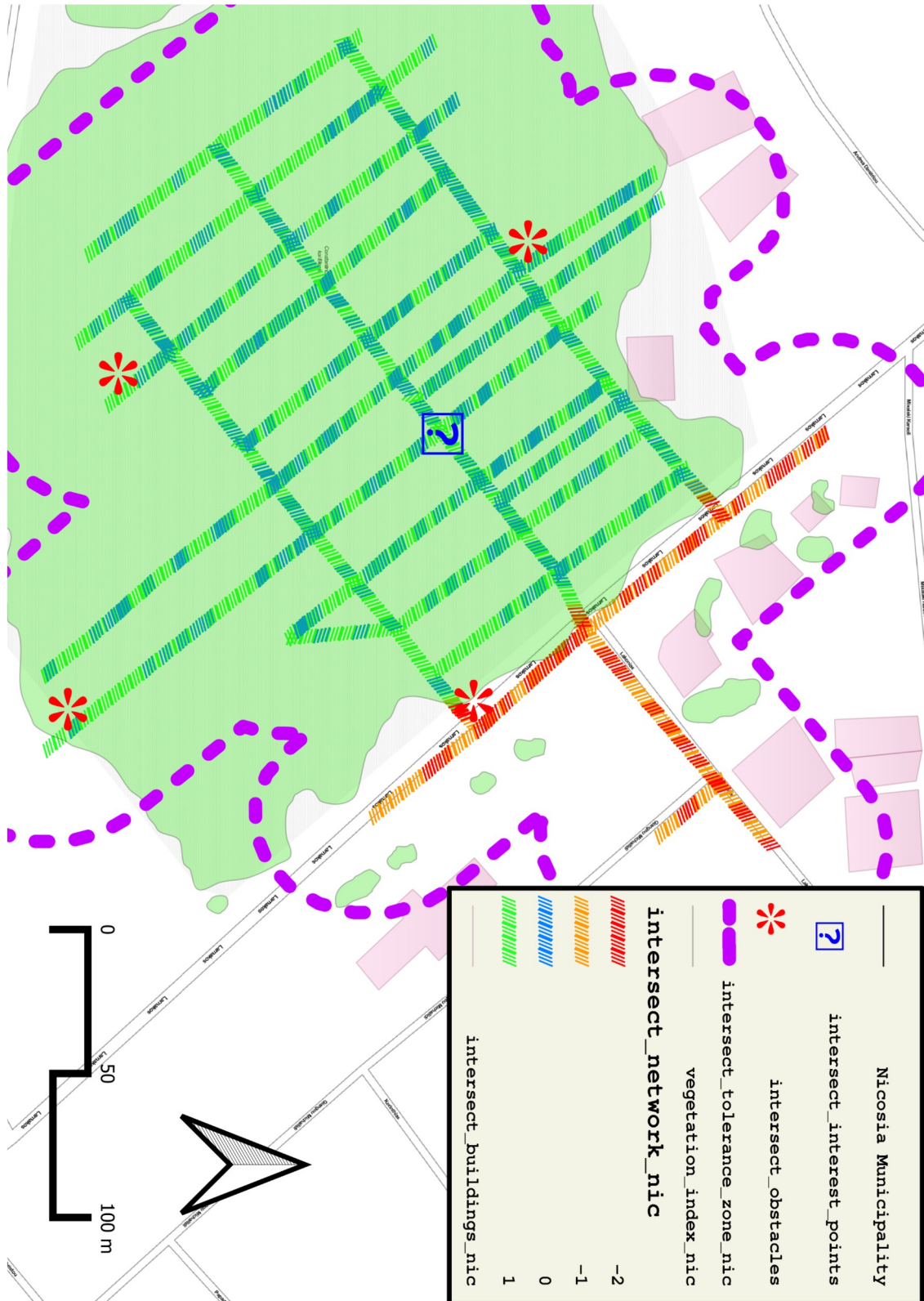
II.1 Agiou Nikolaou Street



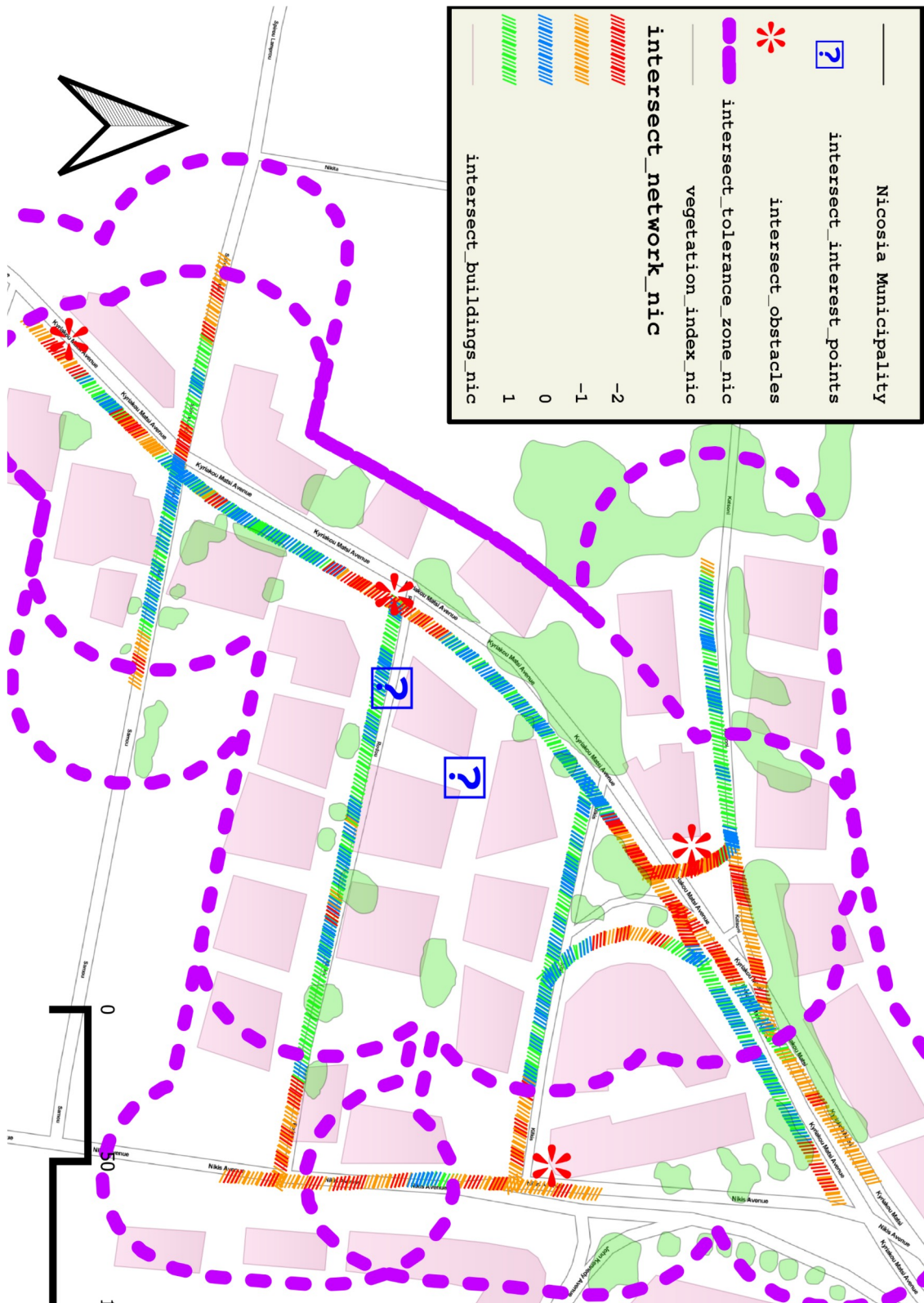
II.2 Florinis Street



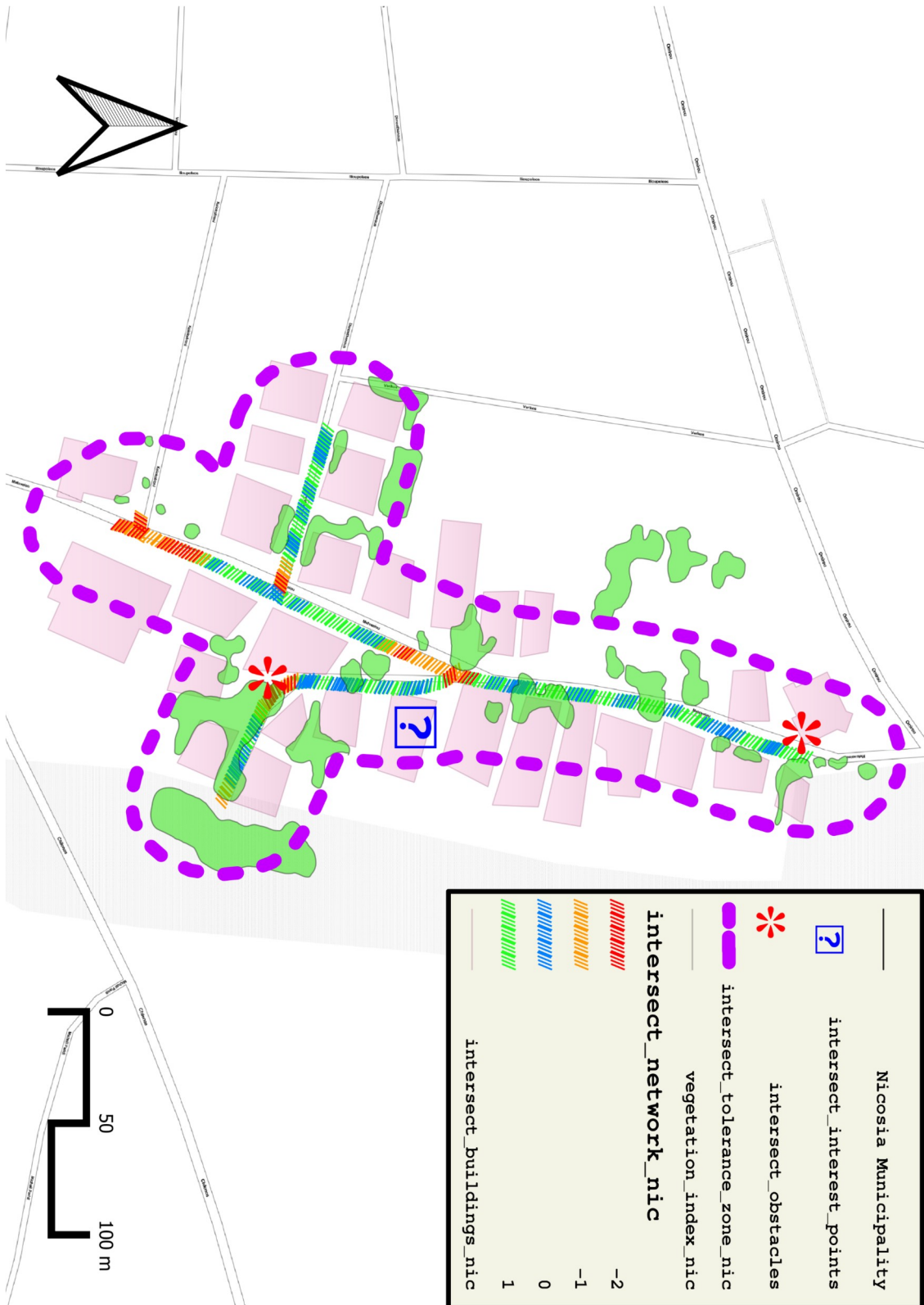
II.3 Konstantinou and Elenis Cemetary



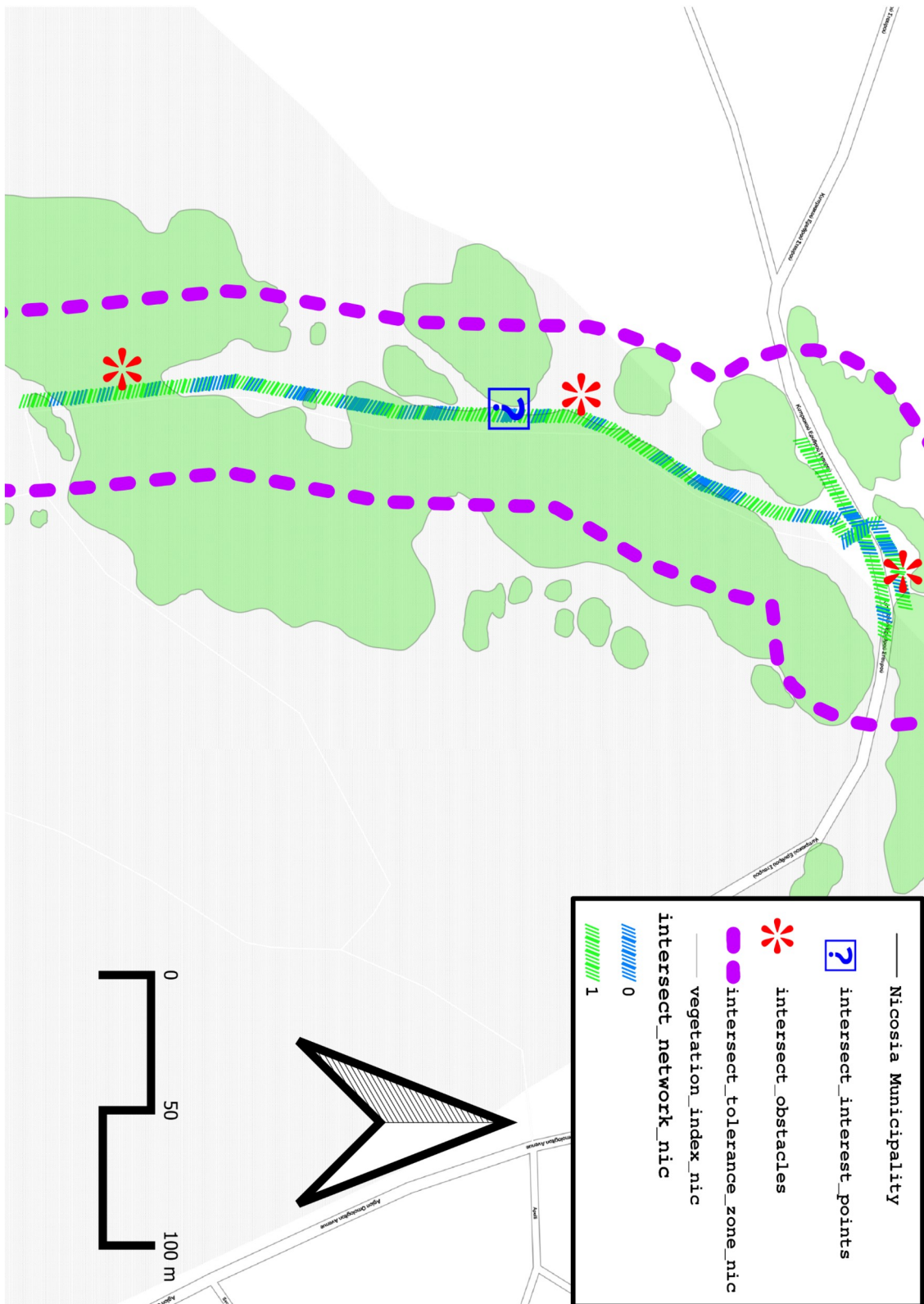
II.4 Kyriakou Matsi Street



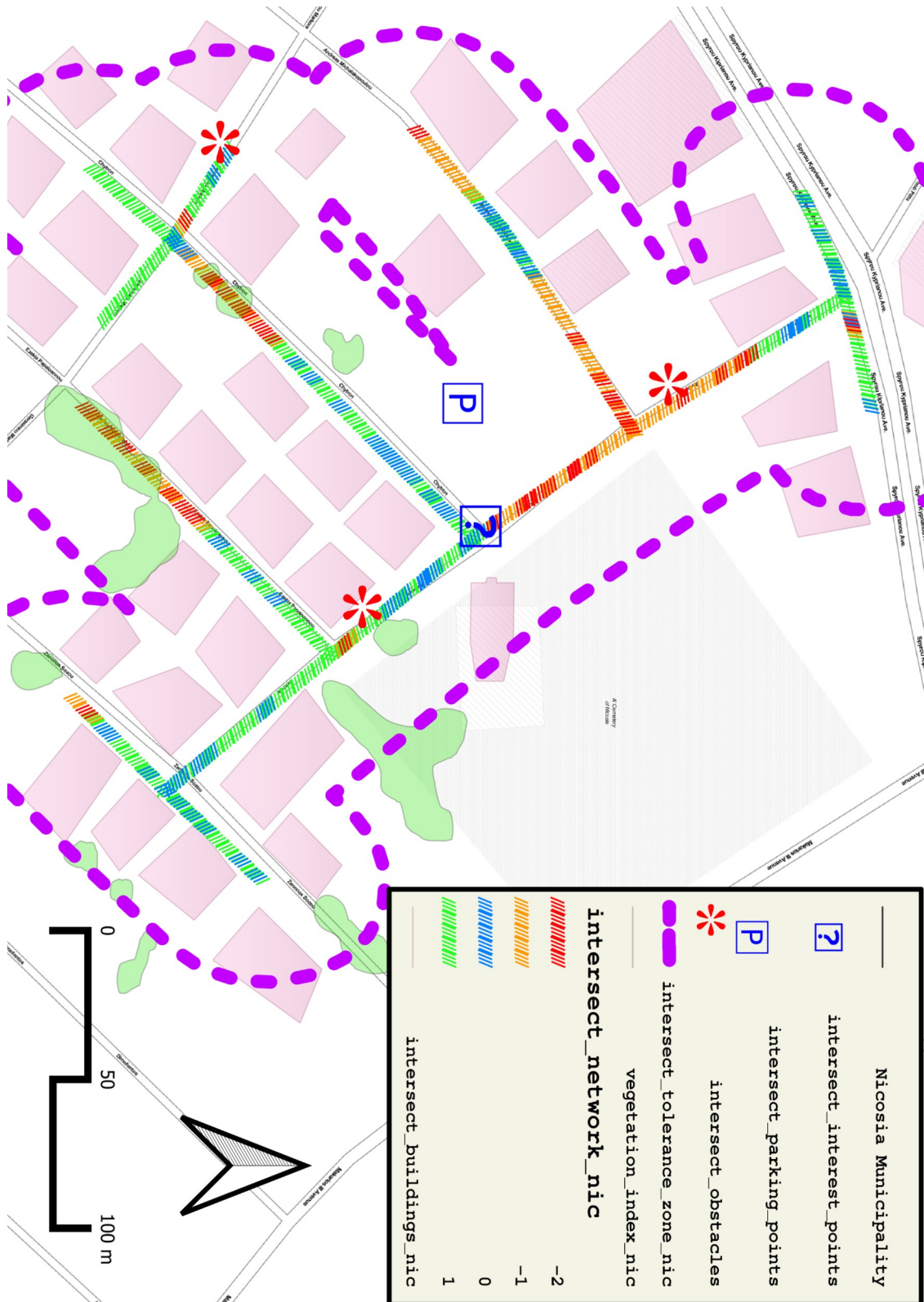
II.5 Metoxiou Street



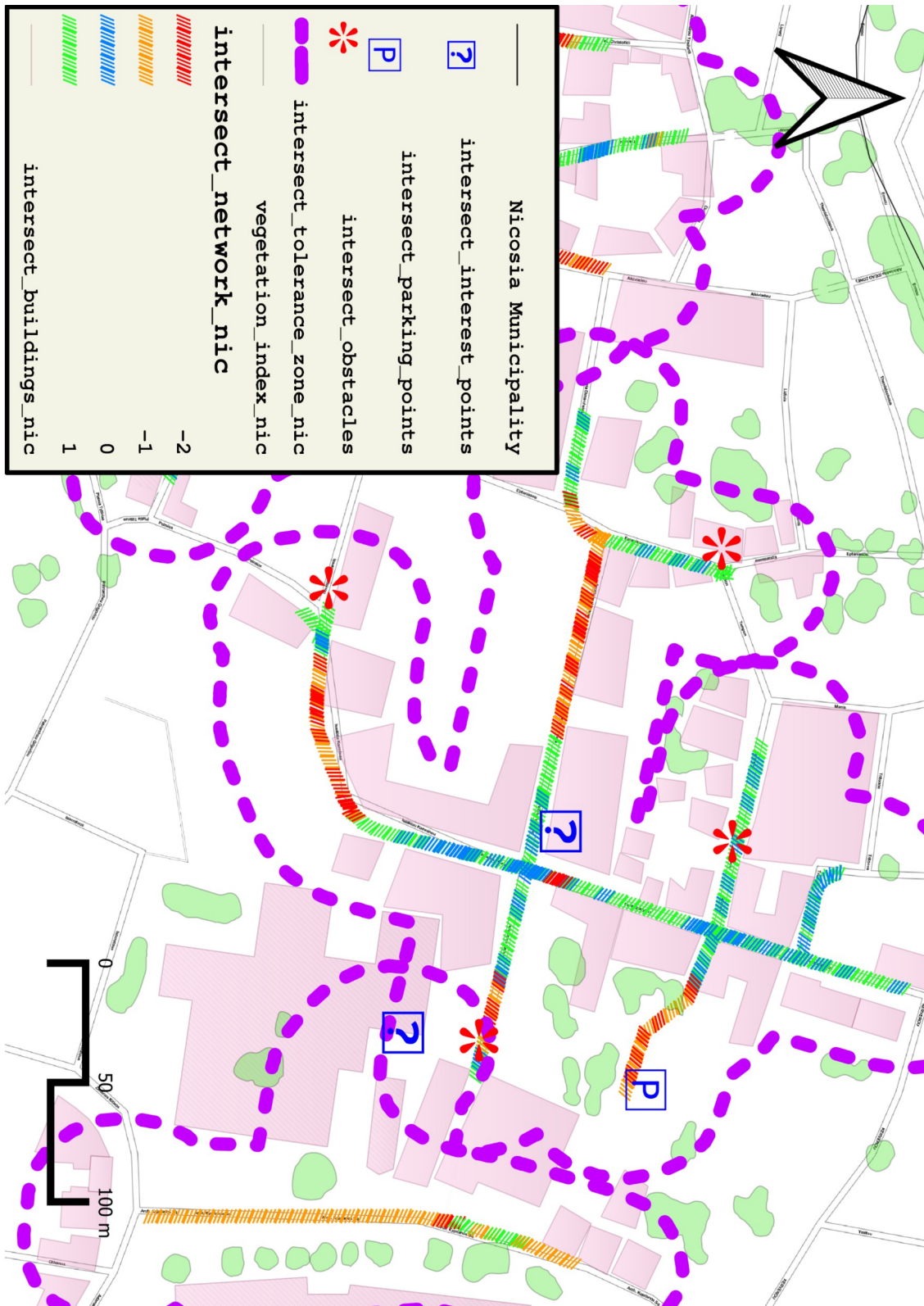
II.6 Presidential Park



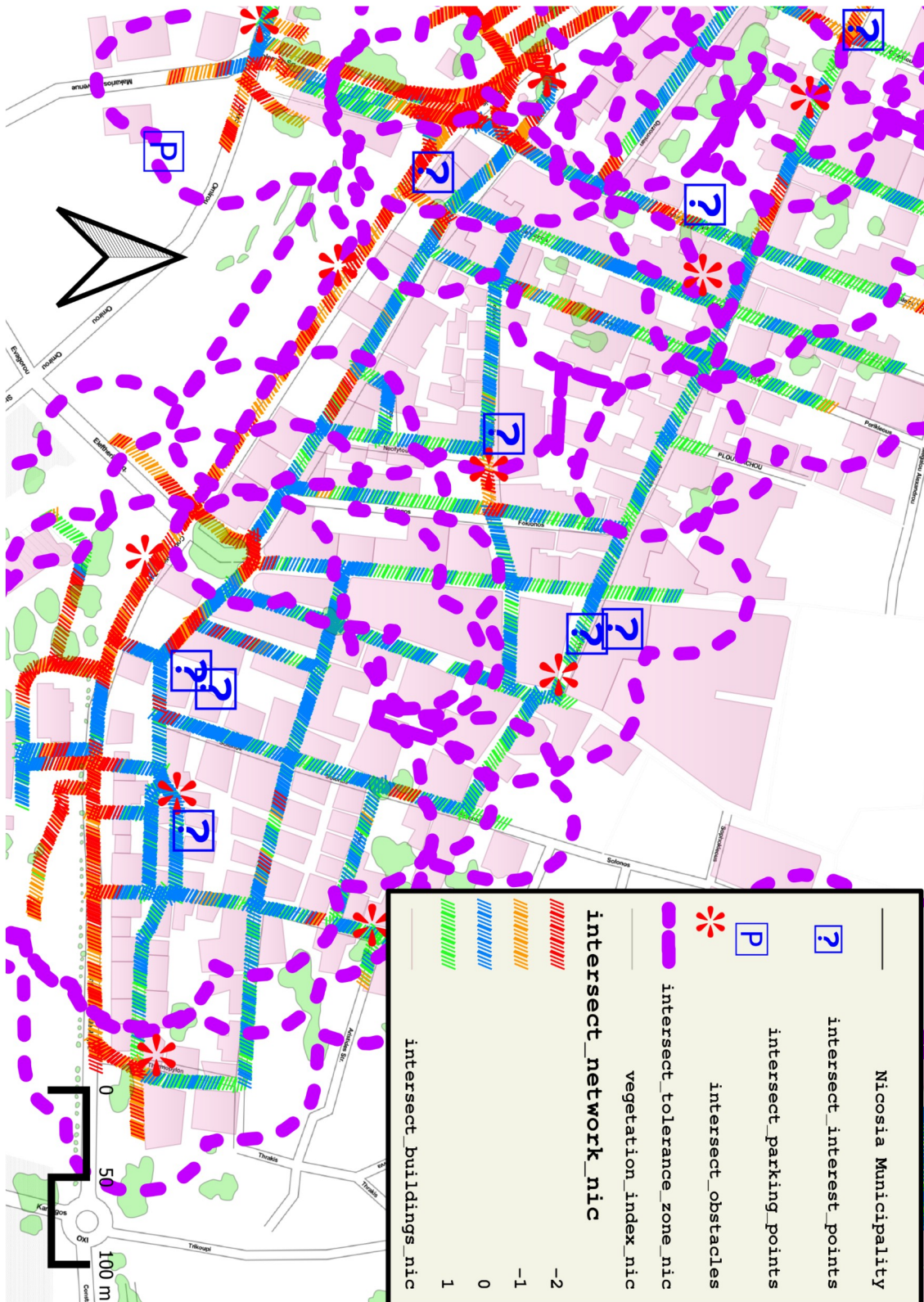
II.7 St. Spyridon Church



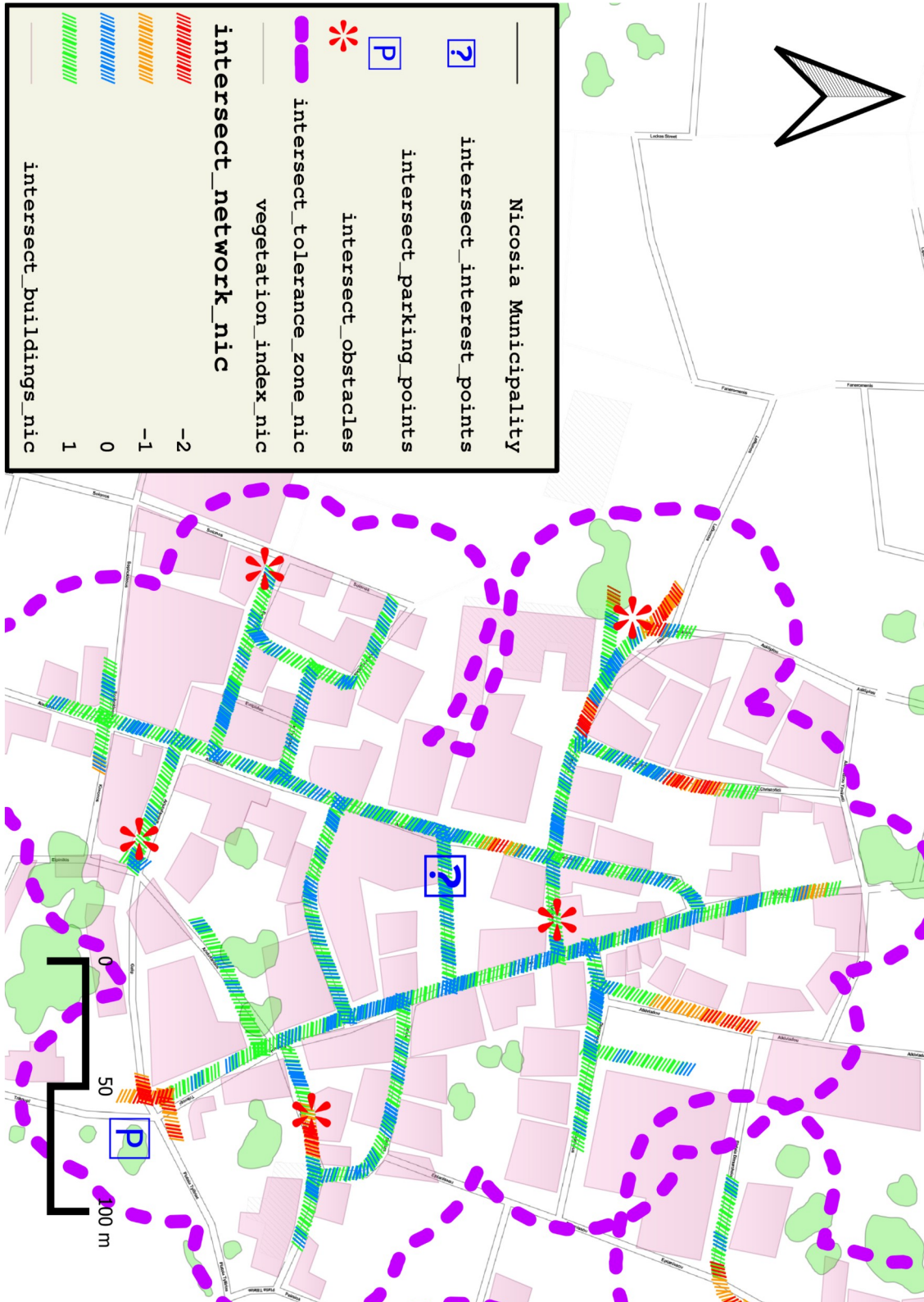
II.8 Walled Old City – Arch. Kyprianou Square



II.10 Walled Old City – Town Hall



II.11 Walled Old City – Trikoupi Street



References

Cambra, P. (2012) *Pedestrian Accessibility and Attractiveness Indicators for Walkability Assessment, Engineering and Architecture*.

Commission, P. (2009) 'Urban Design Handbook', *City*.

Giles-Corti, B. *et al.* (2016) 'City planning and population health: a global challenge', *The Lancet*. doi: 10.1016/S0140-6736(16)30066-6.

Kovacs, K. F. *et al.* (2013) 'The marginal cost of carbon abatement from planting street trees in New York City', *Ecological Economics*. doi: 10.1016/j.ecolecon.2013.08.012.

De La Barrera, F. and Henríquez, C. (2017) 'Monitoring the Change in Urban Vegetation in 13 Chilean Cities Located in a Rainfall Gradient. What is the Contribution of the Widespread Creation of New Urban Parks?', in *IOP Conference Series: Materials Science and Engineering*. doi: 10.1088/1757-899X/245/7/072023.

May, A. D. (2015) 'Encouraging good practice in the development of Sustainable Urban Mobility Plans', *Case Studies on Transport Policy*, 3(1). doi: 10.1016/j.cstp.2014.09.001.

Miranda, H. de F. and Rodrigues da Silva, A. N. (2012) 'Benchmarking sustainable urban mobility: The case of Curitiba, Brazil', *Transport Policy*. doi: 10.1016/j.tranpol.2012.03.009.

Moeinaddini, M., Asadi-Shekari, Z. and Zaly Shah, M. (2015) 'An urban mobility index for evaluating and reducing private motorized trips', *Measurement: Journal of the International Measurement Confederation*. doi: 10.1016/j.measurement.2014.11.026.

Mohamad Nor, S. N. *et al.* (2017) 'Analysis of Pedestrian Gap Acceptance and Crossing Decision in Kuala Lumpur', *MATEC Web of Conferences*. doi: 10.1051/mateconf/201710308014.

Moura, F., Cambra, P. and Gonçalves, A. (2011) 'Pedestrian accessibility and attractiveness assessment tool when planning for walkability', pp. 1–18.

Pant, P. and Harrison, R. M. (2013) 'Estimation of the contribution of road traffic emissions to particulate matter concentrations from field measurements: A review', *Atmospheric Environment*. doi: 10.1016/j.atmosenv.2013.04.028.

Rismanchian, O., Bell, S. and Mokhtarzadeh, S. (2012) 'Identifying accessibility problems in deteriorated urban areas, a case study of Tehran, Iran', in *8th International Space Syntax Symposium*.

Vieira, J. *et al.* (2018) 'Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks', *Environmental Research*. doi: 10.1016/j.envres.2017.10.006.

Wang, Y. and Akbari, H. (2016) 'The effects of street tree planting on Urban Heat Island mitigation in Montreal', *Sustainable Cities and Society*, 27. doi: 10.1016/j.scs.2016.04.013.

Zhang, K. and Batterman, S. (2013) 'Air pollution and health risks due to vehicle traffic', *Science of the Total Environment*. doi: 10.1016/j.scitotenv.2013.01.074.