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Settlements along Main Road Axes: Blessing or Curse? Evaluating the Barrier Effect in a Small Greek Settlement

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Abstract: Being the heart of every human settlement, the road network constitutes a significant component of the built environment that serves the accessibility and mobility needs and supports economic activities. Despite its positive role, the road network, in some cases, due to increased geometric and functional characteristics, can act as a barrier to the movement of vulnerable road users, thus fragmenting the urban space and creating the phenomenon of the "barrier effect". The barrier effect is considered detrimental to the mobility of vulnerable users, causing delays or even cancellation of trips, increasing collision risk, limiting access to services, posing negative impacts on public health, and loosening social ties. In this context, the current paper focuses on a settlement in Greece (Dispilio) developed along two national roads and comprehensively evaluates the barrier effect. More specifically, the presented methodological approach attempts to investigate the actual and the perceived dimension of this phenomenon by applying well-established metrics and landscape indicators, such as the effective mesh size, and conducting a questionnaire survey, respectively. The overall research results highlighted interesting findings regarding the intensity of the barrier effect in the examined area and outlined some critical interventions that could be implemented in similar cases.

Keywords: barrier effect; community severance; fragmentation; effective mesh size; extra travel distance; questionnaire survey; Greece

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1. Introduction

Traditionally, the development of human settlements along main road axes serving connections on regional and national scales was common practice in many countries. This linear type of development, applied over several decades mainly to small-sized settlements, such as towns and villages, was driven by the capacity of regional and national roads to reduce the social isolation of these communities, contribute to their economic growth and openness, and provide enhanced access to adjacent destinations, employment opportunities, education, recreation facilities and health services [1–7]. Although the presence of main road axes was a "blessing" in terms of regional accessibility, over the years, people living in such settlements started to realise that, at the same time, it is a "curse" hindering movements on the local scale [8].

More specifically, road infrastructure and motorised traffic often act as a barrier to the movement of vulnerable users such as pedestrians and bicyclists, thus fragmenting the urban space and creating the "barrier effect" [9]. This phenomenon, also known as "community severance" as the two terms are typically used interchangeably [8,10–14] despite the fact that the latter often embraces a broader range of impacts on local communities [9,15,16], is the result of the presence in the built environment of various static, dynamic or psychological barriers [13,17,18]. Although the elements of the built environment that could act as such vary considerably, restricted-access transport infrastructure that prevents crossing, including railways, motorways, dual carriageways, and multi-laned freeways, comprise the most typical example of physical, static barriers [8,9,11,16,18]. Roads with poorer geometric characteristics yet serving high traffic volumes and speeds (e.g., regional and national networks) might not constitute a constant barrier; however, they are also considered to hamper crossing and thus are characterised as dynamic barriers [8,14,17,19,20]. Finally, even when roads are physically crossable, the lack of a pleasant, safe, secure, well-designed, and adequately maintained pedestrian and bicycle environment could also disrupt their movement and is often considered a psychological barrier [13,17]. A schematic design of the different types of barriers described above is presented in Figure 1.

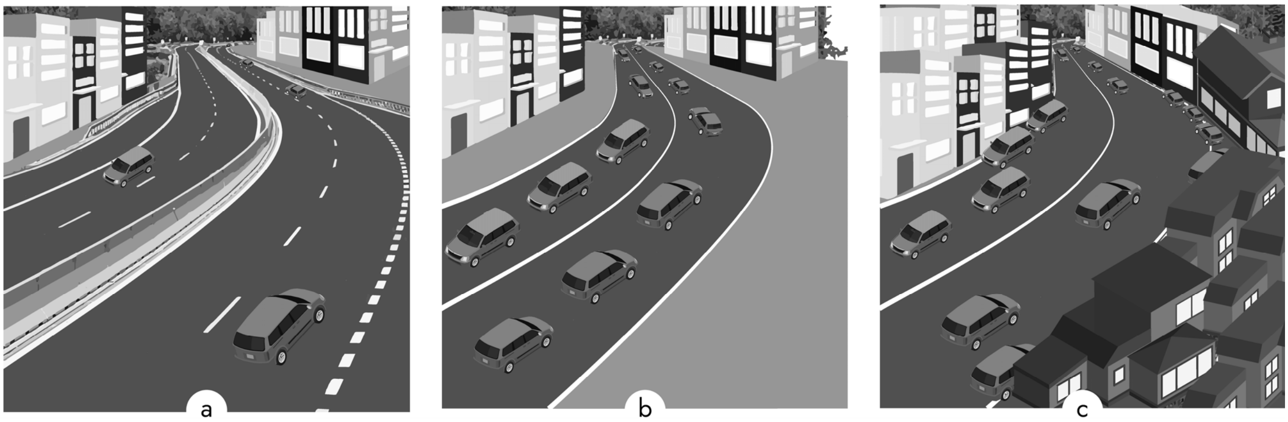

Figure 1. A schematic design of (**a**) physical, (**b**) dynamic, and (**c**) psychological barriers.

The barrier effect of the road infrastructure and motorised traffic is considered to bring about a chain of direct and indirect detrimental impacts on vulnerable road users and the local communities [21]. This complex mechanism or chain of causality, first identified by Korner (1979), consists of three main levels [9,12,22]. First, the various barriers found in the built environment cause detours and delays in walking and bicycle trips, thus reducing the physical accessibility of workplaces as well as essential facilities and local services, such as education, health, social welfare, retail, financial services, recreation, and public transport [6,23]. Moreover, in the case of risk-taking vulnerable users, the barrier effect seriously impacts road safety by increasing the frequency and severity of collisions [9,24,25]. Besides the aforementioned disrupting role on non-motorised trips, the reduction of efficiency of other services, such as urban logistics and waste collection, is also included in the primary, direct impacts of the barrier effect [8,12]. At the secondary level, the primary impacts described above trigger a behavioural change in mobility patterns [8,12]. This behavioural change results in trip cancellations and discouragement of physical activity, a drop in trip frequency, a mode shift in favour of motorised modes, and an alteration of the final destination and the followed route [8,12,16]. Finally, at the tertiary level, the above change in travel behaviour further leads to negative consequences on health and society [8,12]. More specifically, as presented in the literature, the barrier effect is often related to stress amplification, physical and mental health pressures, and deterioration of well-being [18,26–31]. Moreover, the barrier effect is a leading cause of sharpening social inequalities and exclusion, degradation and isolation of neighbourhoods, loss of social ties and diminishment of interactions, especially for children and the elderly [8,12,31]. In line with the above, the studies conducted by Appleyard and Lintell (1972), Sauter and Hüttenmoser (2008), and Hart and Parkhurst (2011), after examining streets with similar characteristics but different traffic volume and speed, highlighted an inverse relationship between the number of neighbourhood social contacts and the level of motorised traffic [9,10,13,32–34].

Despite the great evidence of the barrier effect's adverse impacts presented above, the developed methodological approaches aiming to evaluate this phenomenon and the case studies conducted to better understand it are rather limited and mainly focused on the urban environment [9,16]. In this context, the current paper follows a comprehensive methodological approach utilising well-established indicators from the fields of landscape fragmentation and accessibility as well as a revealed preference survey to assess the actual and perceived dimensions of the barrier effect in a small rural settlement in Greece.

The remainder of the paper is organised as follows. First, an analysis of the relevant literature is presented in Section 2. Next, the methodological approach followed to evaluate the phenomenon of the barrier effect is described explicitly in Section 3. Then, the results are illustrated and discussed in Section 4. Finally, the paper's main conclusions are drawn in the last section (Section 5).

2. Background

To build on the previous efforts conducted to evaluate the barrier effect, a systematic literature review was carried out. To this end, a process consisting of several steps was applied. This process is illustrated in Figure 2 below.

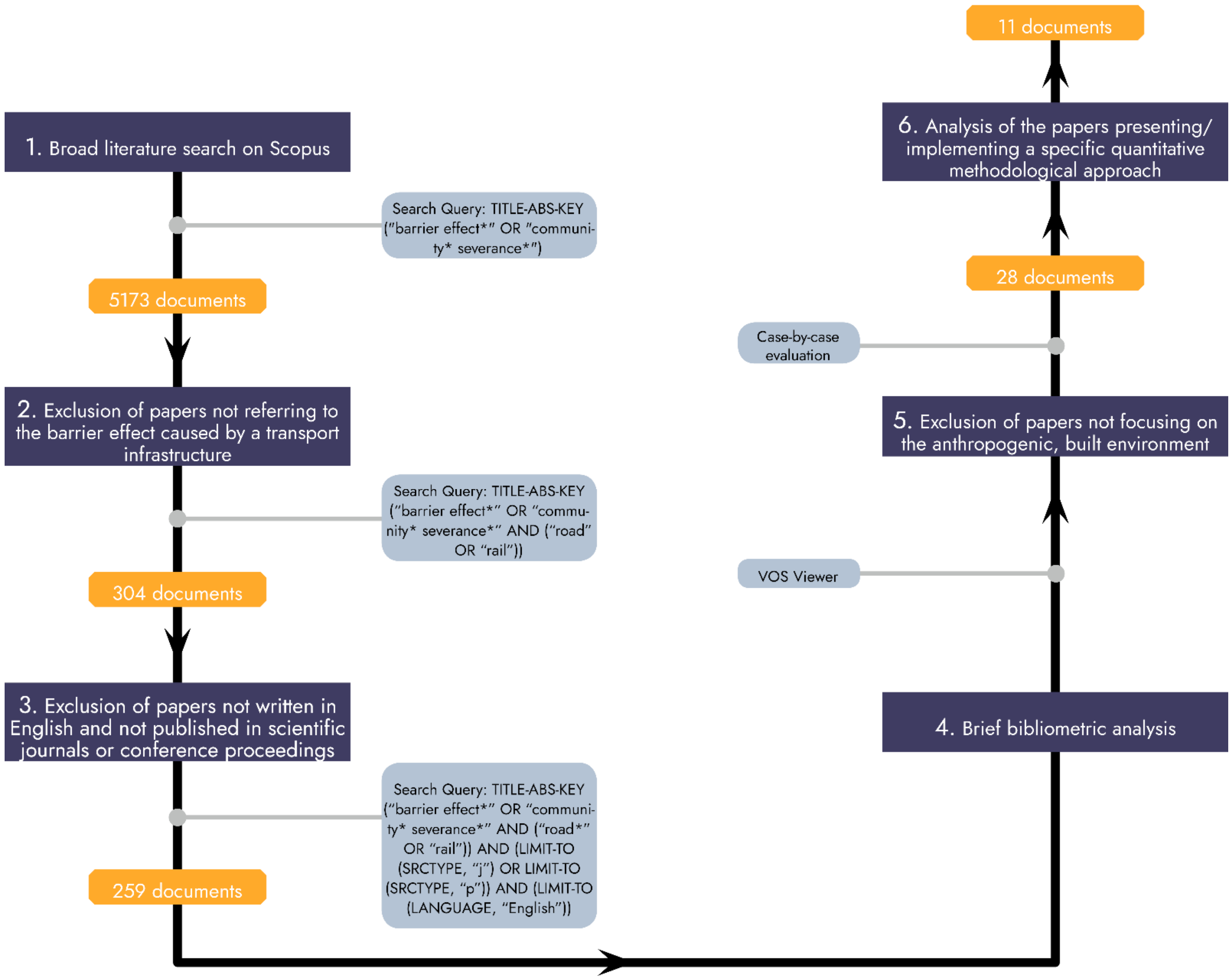

Figure 2. The steps composing the systematic literature review process.

First, an initial search on the Scopus database [35] was made using the relevant terms "barrier effect*" and "community* severance*". Scopus was selected as one database achieving a satisfactory balance between the quantity and quality of the indexed journals and providing easy access to various metrics, thus making it more suitable for practical analyses [36–38]. The aforementioned search returned the documents where these terms appear in the title, abstract, or keywords and led to a list of 5173 results. Next, a stricter filter limiting the initial search was considered necessary to exclude papers not referring to the barrier effect caused by a transport infrastructure. Thus, a significantly smaller list of 304 documents was created. In the third step, the documents not written in English and not being published in scientific journals or conference proceedings were further excluded resulting in an updated list of 259 documents. Using this refined list as input, a brief bibliometric analysis was conducted mainly using the VOS Viewer software [39]. The goal of this analysis, whose results are illustrated in Figures 3 and 4, was to gain a first insight into the evolution of the relevant literature over time as well as its context.

As shown in Figure 3, even though the first documents examining the barrier effect were published over four decades ago, the significantly larger share of literature refers to the last 10 to 15 years. Regarding the analysis presented in Figure 4, keywords such as animals, typically related to the adjacent fields of landscape and habitat fragmentation, are also found to play a key role here. Thus, given that the current paper focuses only on the anthropogenic, built environment, the eligibility of each of the 259 documents was evaluated on a case-by-case basis leading to a short list of 28 relevant papers. Even though these papers were all considered, only those presenting or implementing a specific quantitative methodological approach to evaluate the barrier effect were selected to be described in more detail. Thus, the description of these 11 methodological approaches is as follows.

Anciaes (2013), in his first approach, included three (3) GIS-based indicators to measure and appraise the barrier effect caused by the introduction of a new urban motorway in the Lisbon metropolitan area, Portugal [23]. Among others, he estimated the share of the population affected by the different barriers and barrier effect intensity [23].

A few years later, Anciaes et al. (2018) conducted a stated preference survey in areas of London and Birmingham, UK, surrounded by major roads, to estimate the value of reductions in the barrier effect [11]. Through their study, monetary values were identified for many different interventions towards reducing the barrier effect, including changes in road design and lowering motorised traffic levels [11].

Similarly, Maciorowski and Souza (2018) examined the barrier effect in the city of Florianopolis, Brazil [31]. More specifically, after capturing through a questionnaire survey the socio-economic profile of the local residents as well as their perception regarding the act of the SC 401 highway as a barrier, they conducted a stated preference exercise to assess the potential of implementing remedial actions [40].

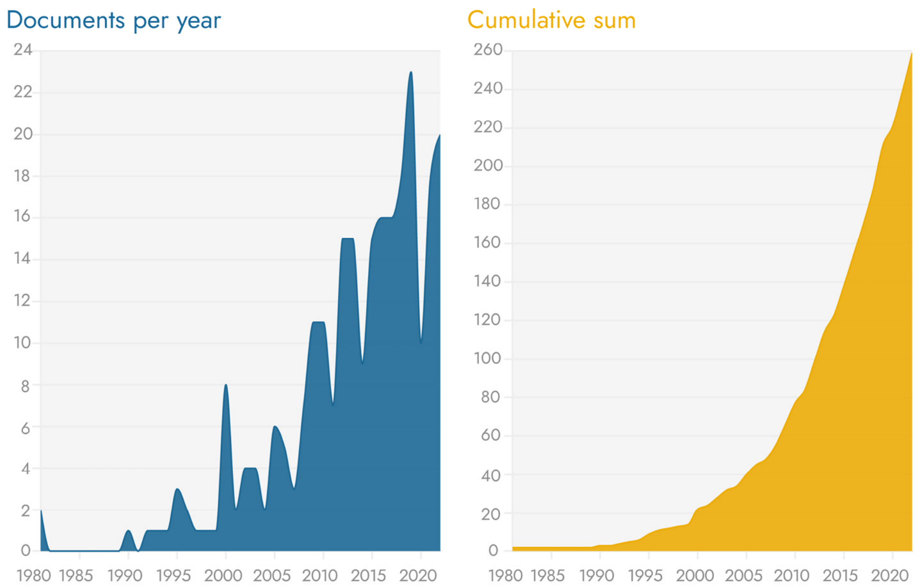

Figure 3. Evolution over time of the relevant literature.

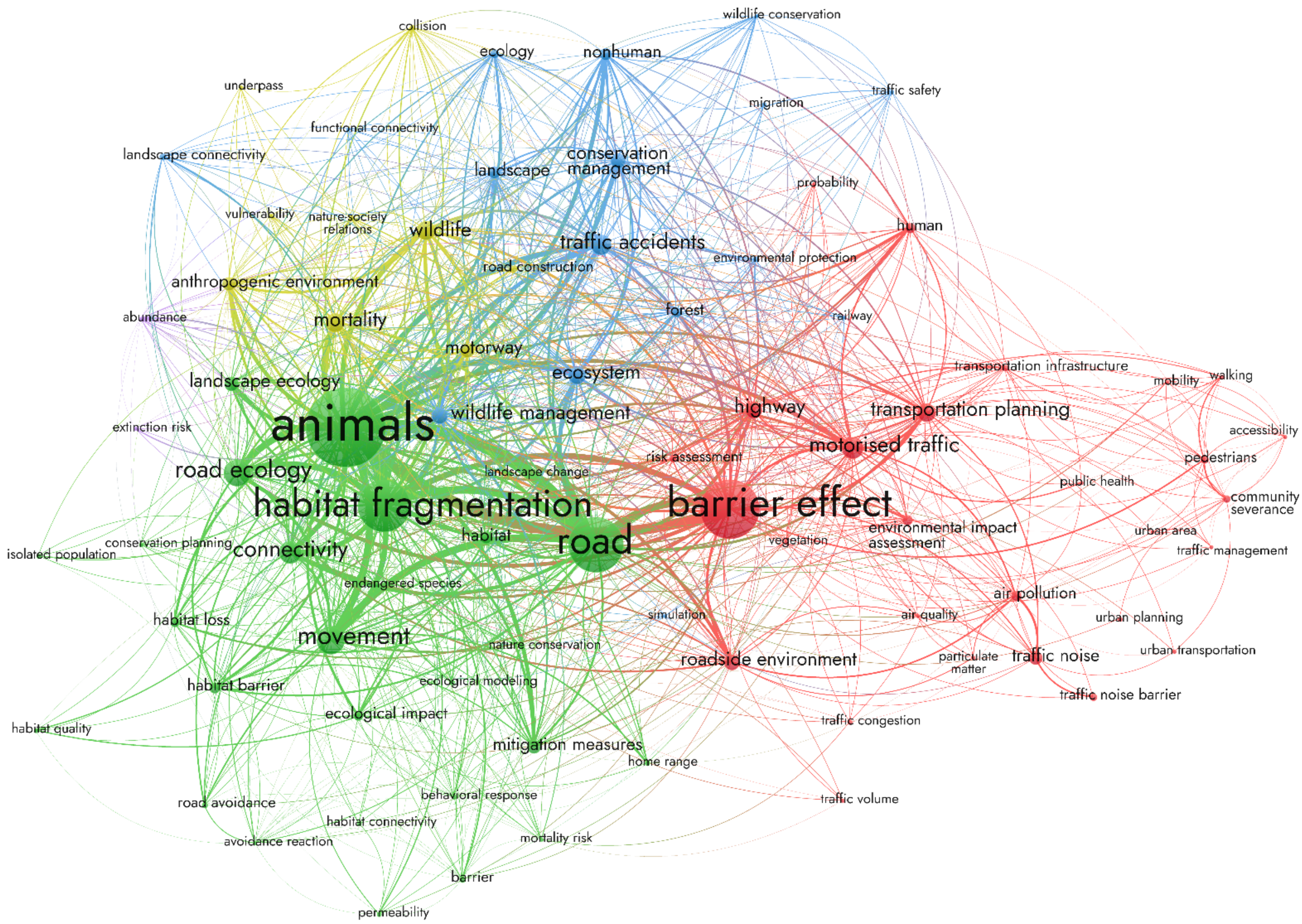

Figure 4. Keyword co-occurrence analysis of the relevant literature.

Recognising the lack of a universal standard for appraising the barrier effect, Mindell et al. (2017) developed a toolkit consisting of seven (7) components, i.e., participatory mapping, spatial analysis, video survey, street audits, health and neighbourhood mobility survey, and a stated preference questionnaire survey. As a case study, Mindell et al. (2017) applied their toolkit on a major road in North London, UK [16].

Focusing on a railway infrastructure rather than a road axis, Lara and Rodrigues da Silva (2019) followed a methodological approach to assess the barrier effect in the city of São Carlos, Brazil [31]. Using georeferenced census data, they compared through the chi-square (χ^2) test of independence and standardised Pearson residual the socio-economic characteristics of people living near five (5) different types of crossings (i.e., level crossing, overpass, underpass, pedestrian crossing, no crossing) and found significant correlations [31]. In the second stage, Lara and Rodrigues da Silva (2020) adapted their methodological approach to consider road barriers. They applied it accordingly to a sample of 100 randomly selected segments in the same city of São Carlos, Brazil, further confirming their primary findings [31]. Building upon their previous studies, Jesus and Rodrigues da Silva (2022) examined through a questionnaire survey residents' perceptions regarding the potential role of high traffic volume and speed to act as a dynamic barrier [14]. To this end, they developed a Decision Tree and Random Forest classification models [14].

Anciaes and Jones (2020) introduced an index that assesses and values the barrier effect at a given point along a road axis [9]. The main components used for constructing their index were two stated and revealed preferences questionnaire surveys carried out in two medium-sized cities (Hereford and Hull) in the UK [9].

Contrary to the vast majority of the other approaches that implemented a questionnaire survey, Eldijk et al. (2020) utilised four (4) accessibility, GIS-based indicators to assess the barrier effect in terms of (a) travel time, (b) the number of destinations reached within a given time, (c) the number of households reached within a given time, and (d) time of public service vehicles (e.g., waste collection, ambulances) trips [8,12]. These indicators were calculated as a pilot in the north of Gothenburg, Sweden, surrounded by significant roadway and railway axes [8,12].

Finally, using the data collected from an online panel survey of 4111 participants in the UK, Higgsmith et al. (2022) constructed the "Community Severance Index" that linked the barrier effect with the self-rated health level [13]. In line with previous findings in the literature, their results highlighted an inverse relationship between the barrier effect and well-being [13].

3. Materials and Methods

3.1. Overview

Drawing from the existing literature described above, the current paper follows a comprehensive approach to evaluate the actual and perceived dimensions of the barrier effect in a small rural settlement in Northern Greece. To this end, the present methodological approach embeds three tools deriving from different fields and perspectives, i.e., the calculation of a landscape indicator, the estimation of an accessibility indicator, and the conduction of a questionnaire survey. These three methodological components and the study area are explicitly described above.

3.2. Description of the Study Area

The area selected for applying the methodological approach was the settlement of Dispilio, Greece. Dispilio is a small, in terms of area and population (0.31 km^2 and 976 inhabitants, respectively [41]), rural settlement located near the city of Kastoria in Northern Greece. The settlement of Dispilio, named after the adjacent lakeside Neolithic settlement [42], was developed along two major road axes accommodating mainly through movements, i.e., the National Road 15 connecting the cities of Kastoria and Argos Orestiko and the Old National Road 15 linking the city of Kastoria with the area of Amyntaio. As these road axes meet within the settlement of Dispilio at a T-intersection, three (3) discrete zones (A, B, and C) composing the study area were created. The predominant land use in all three zones and across the study area is residential, whilst some commercial uses, such as supermarkets, gas stations, and clothing stores, are also found along the aforementioned road axes. These two-way roads featuring a width of 10 m, are composed of one lane per direction, while parking is prohibited throughout their length [43]. Based on field observations and in-situ measurements carried out in Dispilio, the area significantly lacks pedestrian crossings, while at the same time, any attempt to cross the two major roads is harshly hampered by their high traffic volumes [43]. More explicitly, according to these measurements, each of the abovementioned roads serves more than 1050 vehicles on a typical peak hour period, thus equalling a pace of almost 18 vehicles per minute or, in other words, one vehicle every three seconds [43]. It should be pointed out here that these traffic volumes, combined with the geometric design of these roads, are far from providing an acceptable, safe crossing gap for vulnerable users [43,44]. Furthermore, although reduced speed limits (30–50 km/h) are applied to these two roads within the study area's boundaries, the measurements highlighted a severe speeding problem, with the average traffic speed far exceeding 65 km/h [43]. In this context, despite providing regional accessibility and facilitating the connection of Dispilio with the adjacent cities contributing thus to its economic development, it is more than clear that the two national roads, serving high traffic volumes and speeds throughout the year, hinder vulnerable users' movements and thus act as barriers.

The settlement of Dispilio comprising the study area is illustrated in Figure 5 below.

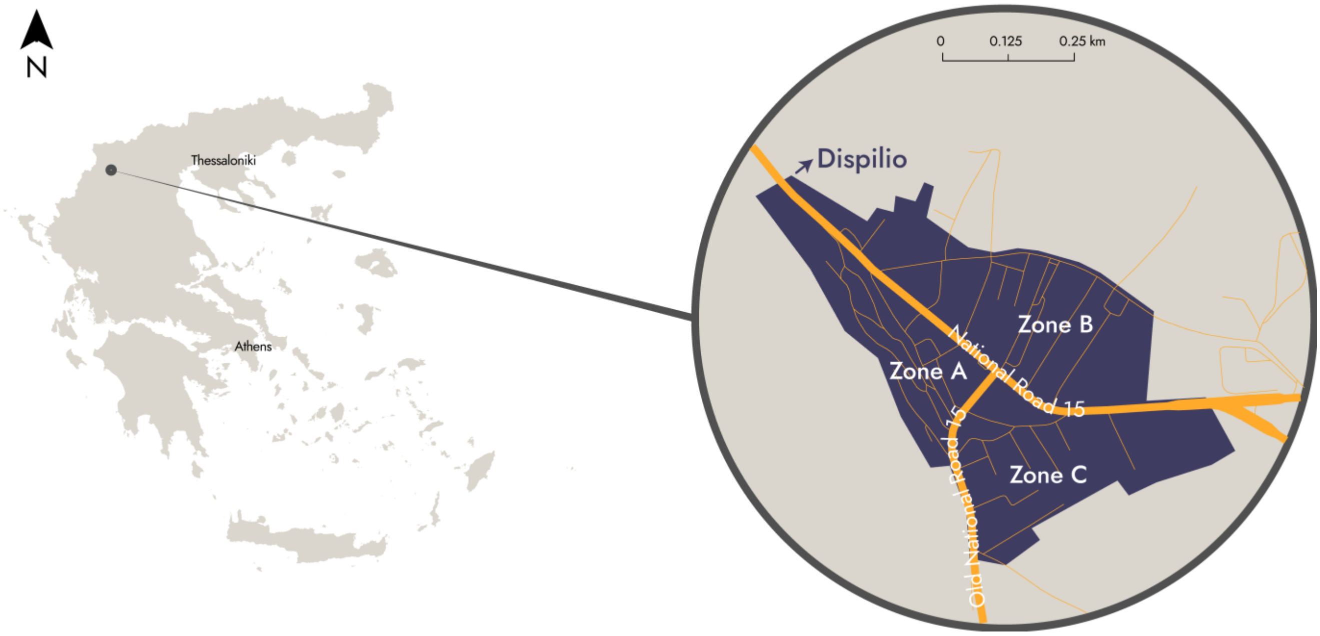

Figure 5. The settlement of Dispilio.

3.3. Description of the Main Methodological Components

3.3.1. Calculating the Landscape Indicator "Effective Mesh Size, m_{eff}"

To thoroughly assess the barrier effect, the well-established indicator of "effective mesh size, m_{eff}" was included in the developed methodological approach. The effective mesh size was introduced by Jaeger (2000) almost two decades ago and, over the years, has become one of the most widely used and accepted landscape fragmentation indicators, being heavily applied in studies in many different regions and countries, including those carried out by the European Environment Agency [45–51].

As shown in Figure 6 below, the main concept behind this indicator is the probability of two (2) points randomly selected within an area being connected, i.e., being in the same patch or, in other words, not separated by a barrier, such as a motorway [45].

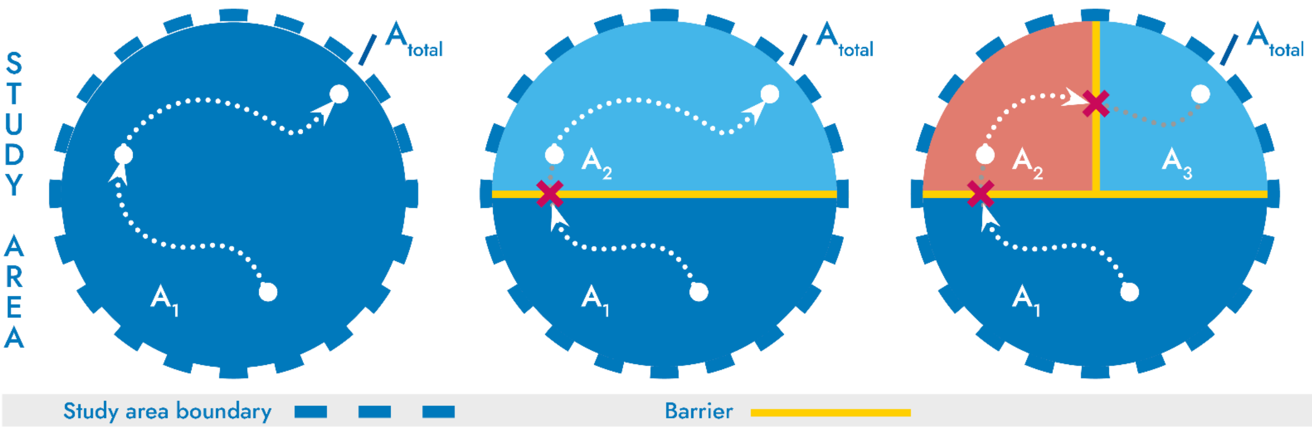

Figure 6. The main concept of the effective mesh size.

Even though the effective mesh size in its original field of landscape ecology could be interpreted as "the average size of an area that an animal placed randomly in the landscape is able to access without having to cross a barrier" [48] or the probability of "two animals placed in different locations being able to find each other without having to cross a barrier such as a road or a railway" [45], it is more than clear that the same indicator could also be utilised as a robust metric in other fields [47], including the built environment. Thus, in the context of the presented methodological approach, the basic idea of the effective mesh size is modified as the probability of two (2) vulnerable users randomly selected within the study area being connected and not separated by a barrier.

According to the literature, two alternative procedures can be followed to calculate the effective mesh size, namely, the original CUT (Cutting-out) procedure and the more recent CBC (Cross-Boundary-Connections), which addresses the inherent boundary problem characterising the first (i.e., the administrative boundaries are treated as additional barriers) [45,52]. However, given that the study area examined in this paper is not divided into different parts by an administrative boundary, and for the sake of simplicity, the CUT procedure was selected. Thus, the effective mesh size was calculated as follows:

$$m_{eff} = \left(\left(\frac{A_1}{A_{total}}\right)^2 + \left(\frac{A_2}{A_{total}}\right)^2 + \cdots + \left(\frac{A_n}{A_{total}}\right)^2\right) \times A_{total} = \frac{1}{A_{total}} \sum_{i=1}^{n} A_i^2 \quad (1)$$

where A_{total} is the total size of the study area (reporting unit), n is the number of patches inside the study area, and A_1 to A_n is the size of the n patches [45].

Aiming to facilitate the interpretation of the results, the aforementioned calculated indicator was converted into the scale 0–1 using the transformation below, where 1 is the maximum value reached in an area completely lacking barriers and 0, on the contrary, is the minimum value corresponding to an area entirely covered by transport infrastructure barriers.

$$tm_{eff} = \frac{m_{eff}}{A_{total}} \quad (2)$$

where tm_{eff} is the calculated effective mesh size value transformed into the scale 0–1.

As for data collection and processing, open data sources comprised the basis for all calculations. More specifically, using OpenStreetMap as a base map [53], the polygon shapefile representing the study area was created from scratch in a GIS environment. Similarly, after collecting the road network in a shapefile format from the same service and identifying the various barriers, the line shapefile representing these barriers was created from scratch. Using the abovementioned shapefiles as input and applying the “Split Polygons” tool, a third polygon shapefile was constructed containing the different patches. Finally, by exporting the attribute of each patch’s area (size) in spreadsheets, the final value of the described indicator was calculated.

3.3.2. Calculating the Accessibility Indicator “Extra Travel Distance, e_{td}”

Considering the high complexity of the examined phenomenon, an additional indicator, reflecting this time the accessibility perspective, was embedded in the developed methodological approach. More specifically, the second component of the proposed methodological approach focuses on the extra travel distance imposed by the various barriers. It should be noted that this indicator was selected among others, as its results can be easily converted into travel time (by applying a typical walking/biking speed) as well as monetised values [8,12].

In this context, as the scope of the indicator described below is to comprehensively capture the impact of the barrier effect in terms of people’s accessibility, the centroid of every city block located in the study area was considered at the same time as a potential origin and destination. It should be pointed out here that in a large urban environment, the selection of destinations could be limited only to essential urban facilities and services. However, in a small rural settlement, such as Dispilio, where social ties and contacts are enhanced, the comprehensive selection of all city block centroids as destinations was considered more appropriate. Then, using network distances rather than Euclidean, the sum of the walking distances between all O-D (Origins-Destinations) pairs was calculated for two scenarios: (a) the current network as is with the barriers and (b) a similar, ideal network without the barriers. Finally, the indicator e_{td} was calculated as the ratio of these walking distances, as shown in the following equation:

$$e_{td} = \frac{\sum_{i=1}^{n} td_c}{\sum_{i=1}^{n} td_i} \quad (3)$$

where td_c is the network travel distance between each O-D pair in the study area based on the current network, td_i is the network travel distance between each O-D pair in the study area based on the similar ideal network, and n is the number of O-D pairs.

As can be concluded from Equation (3), the indicator values are, in every case, equal to or greater than 1, with those close to 1 highlighting a nearly imperceptible impact of the barrier effect on people's accessibility.

As for data collection and processing, the centroids of city blocks and the road network constituted the necessary input data. Regarding the first, the city blocks of the examined area were gathered in a shapefile format from the Hellenic Statistical Authority [54]. Then, a point shapefile representing city blocks centroids was created by applying the "Feature to Point" tool in the GIS environment. Concerning the second, the shapefile representing the road network of the study area, already collected in the framework of the previous indicator, was used to build a network dataset in the GIS environment. Based on this network dataset and by performing two "O-D (Origin-Destination) cost matrix" analyses corresponding to the scenarios described above, the respective tables containing the length of the least-cost paths from all origins to all destinations were created. Finally, by exporting these tables in spreadsheets, the two sums (Σtd_c and Σtd_i) and the final value of the indicator e_{td} were calculated.

3.3.3. Conducting the Questionnaire Survey

Apart from the previous two indicators that contributed to the actual assessment of the barrier effect, the last component of the followed methodological approach included a revealed preference survey to capture and evaluate people's perceptions about the examining phenomenon. This survey was carried out through in-person "Paper and Pencil Interviews" (PAPI) with the adult residents of Dispilio, Greece, and a fair sample of 100 valid responses was collected, thus giving a rough yet relatively robust representation of the local population's opinions [43]. It should be noted that defining only the adults as the survey population, instead of people of all ages, was driven by ethical and privacy reasons. This sample selected by random spatial sampling method, despite corresponding to approximately 13% of the local adult population and relating to a high share of local households, is on the low side and results in practice in a margin of error of nearly 9% at a confidence level of 95%.

As far as the questionnaire design is concerned, the questionnaire developed for this survey consisted of four (4) main parts [43,55]. More specifically, the first part (Part A) contained eight (8) questions regarding the respondents' socio-economic characteristics, such as their gender, age, occupation, and income level, as well as the relative location (zone) of their home [43,55]. The second part (Part B) included four (4) questions capturing the respondents' trip characteristics, e.g., trip frequency, mode choice, trip purpose, etc. [43,55]. Next, the third part of the questionnaire (Part C) was composed of six (6) questions. These questions focused on the respondents' perceptions of the barrier effect in the case of Dispilio and aimed at capturing the direct and indirect impacts on their mobility behaviour [43,55]. Finally, the survey ended with Part D, where respondents were asked about the perceived level of safety risk when crossing the national road axes as well as their opinions about various mitigating interventions [43,55]. The main variables constructed based on the questionnaire described above are presented in Table 1.

Table 1. Overview of the variables used.

Variable	Description	Range		Type
Zone	Where is your residence located?	1: Zone A 2: Zone B	3: Zone C	Nominal
Gender	To which gender identity do you most identify?	1: Man	2: Woman	Nominal
Age	What is your age?	1: 18–24 2: 25–34 3: 35–44	4: 45–54 5: 55–64 6: 65+	Ordinal
Household Members	How many people live in your household?	1: 1 member 2: 2 members 3: 3 members 4: 4 members	5: 5 members 6: 6 members 7: 7 members	Ordinal
Income	What is your monthly household income?	1: <400€ 2: 400–800€ 3: 800–1200€	4: 1200–1600€ 5: >1600€	Ordinal
Educational Level	What is your educational level?	1: Did not graduate from elementary school 2: Elementary school graduate	3: High school graduate 4: University graduate	Ordinal
Employment Status	What is your employment status?	1: Private-sector employee 2: Public-sector employee 3: Self-employed/Contractor 4: Student	5: Retired 6: Homemaker 7: Other	Nominal
Cars	How many cars does your household own?	1: no car 2: 1 car 3: 2 cars	4: 3 cars 5: 4 cars 6: 5 cars	Ordinal
Motorbikes	How many motorbikes does your household own?	1: no motorbike 2: 1 motorbike 3: 2 motorbikes	4: 3 motorbikes 5: 4 motorbikes 6: 5 motorbikes	Ordinal
Bicycles	How many bicycles does your household own?	1: no bicycle 2: 1 bicycle 3: 2 bicycles	4: 3 bicycles 5: 4 bicycles 6: 5 bicycles	Ordinal
Travel Mode Internal	Which mode of transport do you typically use for trips starting and ending inside the settlement?	1: Car 2: Motorbike 3: Bicycle	4: On foot 5: Other	Nominal
Travel Mode External	Which mode of transport do you typically use for trips starting and/or ending outside the settlement?	1: Car 2: Motorbike 3: Bicycle	4: On foot 5: Bus 6: Other	Nominal
Daily Walking Trips	How many trips do you typically make on foot every day?	Original response		Scale
Walking Trips Purpose	What is the purpose of your most typical walking trip?	1: To/from work 2: To/from school 3: Leisure	4: Family/personal business 5: Shopping	Nominal
Perceived Walking Trip Duration	How long do you feel a typical walking trip lasts?	Original response		Scale
Perceived Delay	How long do you feel you typically have to wait to cross the two road axes?	Original response		Scale
Willingness to Change	How willing are you to change your trip destination to avoid crossing the two road axes?	1: Yes 2: No	3: Maybe	Nominal
Trip Cancellation	Have you ever cancelled a trip to avoid crossing the two road axes?	1: Yes	2: No	Nominal
Perceived Level of Risk	How risky do you consider crossing the two road axes?	1: Very risky 2: Risky 3: Somewhat risky	4: Not risky 5: Not risky at all	Nominal
Ring Road	Do you think that constructing a ring road would mitigate the barrier effect?	1: Yes 2: No	3: Do not Know 4: Under conditions	Nominal
Small-scale interventions	Which of the following interventions would you recommend for mitigating the barrier effect?	1: Traffic signals 2: Pedestrian overpass 3: Pedestrian underpass	4: Pedestrian crossings 5: Speed cushions 6: Traffic enforcement	Nominal

As far as sample representativeness is concerned, a satisfactory sex and age balance similar to the population average reported by the Hellenic Statistical Authority was achieved [43,54,55]. More specifically, males and females are almost equally represented in the sample (51% and 49%, respectively), while the shares of the respondents belonging to the age groups 18–34 and 35–54 were reasonably aligned with the respective populations.

On the other hand, a relatively slight over-representation of individuals aged 55–64 and a similar under-representation of those over 65 years were also observed [43,54,55]. Finally, in line with the characteristics of the target population, the average monthly household income reported by the majority of the respondents falls within the range of 400 to 800€, while a significant share of the sample (46%) has graduated from (junior or senior) high school [43,54,55].

4. Results and Discussion

The application of the three-component methodological approach described above resulted in a comprehensive evaluation of the actual and perceived dimensions of the barrier effect in the settlement of Dispilio.

More specifically, following the identification of the two roads axes passing through the settlement of Dispilio as traffic barriers, which was described before, the study area was divided into three (3) patches (A_1, A_2, A_3) corresponding to zones A, B, and C presented in Figure 5. These relatively similar-sized patches resulted in the calculation of an effective mesh size value of approximately 0.1 km^2 or, based on the proposed transformation, a final value tm_{eff} of 0.353. This value indicates a severely fragmented area where traffic barriers heavily hinder vulnerable users' movements.

In line with the above finding, the outcome of the second examined indicator (i.e., the extra travel distance, e_{td}) further underlines the severe impact of the barrier effect in the case of Dispilio. More explicitly, comparing the total distance between all origins and destinations along the existing network with the respective distance on a similar yet without barriers network, a ratio of 1.25:1 was calculated. This ratio comprising the value of the indicator e_{td} captures the impact of the barrier effect on local accessibility and is indicative of the extra time and cost vulnerable users face due to the presence of the two major road axes. Furthermore, as shown graphically in Figure 7, which results from the same analysis above, a significant share (64.5%) of the O-D connections within the settlement of Dispilio cannot be served without crossing the two main roads. These connections are indicated in this figure in red colour, while for the sake of accuracy, it should also be noted that the thickness of the various lines is proportional to the number of the respective O-D connections in the study area.

Finally, the analysis of the questionnaire survey data using descriptive and inferential statistics performed in the IBM SPSS software [56] also highlighted some interesting findings. More explicitly, as can be concluded from Table 2, which presents the descriptive statistics of the variables used, 87% of the participants own at least one private car, while 65% have one or more bicycles. Concerning mode choice, the great majority (78%) of the internal trips within the settlement of Dispilio are made by active, sustainable modes (i.e., walking and cycling), whereas 69% of the trips starting or ending outside the study area are made by cars. Focusing on walking trips, 6.8 trips per day are made on foot, on average, mainly for shopping (33.6%) and leisure (32.8%). A high share of these trips is made during the morning and evening peak hours (07:00–09:00 and 17:00–19:00, respectively), while their average perceived duration is approximately 6.9 min. Moreover, the average perceived delay experienced due to the two national roads acting as barriers is almost 5.0 min.

Comparing the perceived walking trip duration to the perceived delay, a statistically significant difference is pointed out by a paired sample *t*-test ($t(99) = 3.435$, $p < 0.001$). This finding further enhances the outcomes of the two landscape and accessibility indicators presented before and reconfirms the research hypothesis that the two national roads act as barriers. The boxplots of the aforementioned variables and their underlying distribution, mapped in a way that avoids overlapping, are illustrated in the beeswarm plot in Figure 8.

Table 2. Descriptive statistics of the variables used.

Variable	Frequency		Min	Max	Mean	Standard Deviation
Zone	1: 55% 2: 23%	3: 22%	-	-	-	-
Gender	1: 51%	2: 49%	-	-	-	-
Age	1: 5% 2: 10% 3: 24%	4: 15% 5: 30% 6: 16%	-	-	-	-
Household Members	1: 8% 2: 24% 3: 18% 4: 32%	5: 12% 6: 2% 7: 4%	-	-	-	-
Income	1: 15% 2: 41% 3: 28%	4: 10% 5: 6%	-	-	-	-
Educational Level	1: 2% 2: 35%	3: 46% 4: 17%	-	-	-	-
Employment Status	1: 9% 2: 7% 3: 23% 4: 3%	5: 26% 6: 18% 7: 14%	-	-	-	-
Cars	1: 14% 2: 64% 3: 18%	4: 4% 5: 0% 6: 0%	-	-	-	-
Motorbikes	1: 86% 2: 11% 3: 2%;	4: 1% 5: 0% 6: 0%	-	-	-	-
Bicycles	1: 62% 2: 25% 3: 6%	4: 3% 5: 1% 6: 3%	-	-	-	-
Travel Mode Internal	1: 20% 2: 1% 3: 5%	4: 74% 5: 0%	-	-	-	-
Travel Mode External	1: 65% 2: 2% 3: 3%	4: 0% 5: 30% 6: 0%	-	-	-	-
Average Daily Walking Trips	-		0	20	6.8	4.0
Walking Trips Purpose	1: 13.4% 2: 8.4% 3: 32.8%	4: 11.8% 5: 33.6%	-	-	-	-
Perceived Walking Trip Duration	-		2	20	6.82	3.75
Perceived Delay	-		0.3	20	4.98	3.96
Willingness to Change	1: 44% 2: 50%	3: 6%	-	-	-	-
Trip Cancellation	1: 33%	2: 67%	-	-	-	-
Perceived Level of Risk	1: 82% 2: 15% 3: 2%	4: 1% 5: 0%	-	-	-	-
Ring Road	1: 84% 2: 8%	3: 6% 4: 2%	-	-	-	-
Small-scale interventions	1: 49.2% 2: 18.5% 3: 6.5%	4: 12.9% 5: 4.0% 6: 8.9%	-	-	-	-

To investigate whether the impacts of the barrier effect affect the whole population of the study area or only those living in a specific zone, two One-Way ANOVA tests were conducted. Based on the results, neither the perceived walking trip duration ($F(2.97) = 0.027$, $p > 0.05$) nor the perceived delay ($F(2.97) = 0.908$, $p > 0.05$) is found to be statistically different among the inhabitants of the three (3) zones of the settlement, thus indicating that the barrier effect negatively affects the whole area of Dispilio.

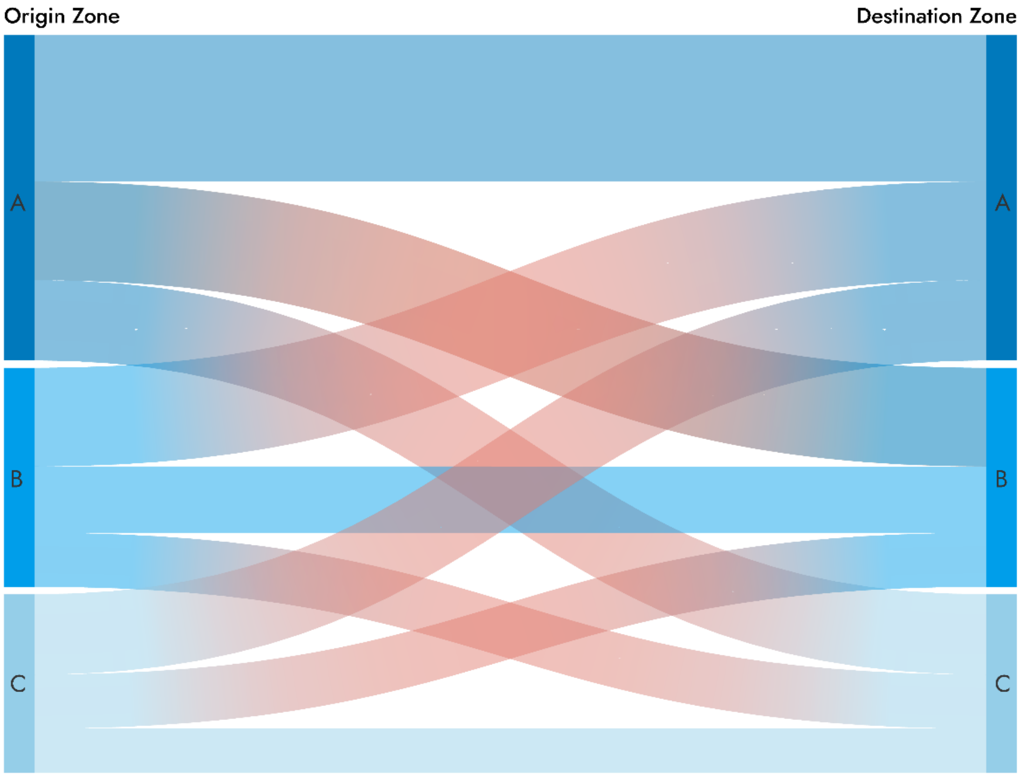

Figure 7. Sankey diagram illustrating the O-D connections in the study area.

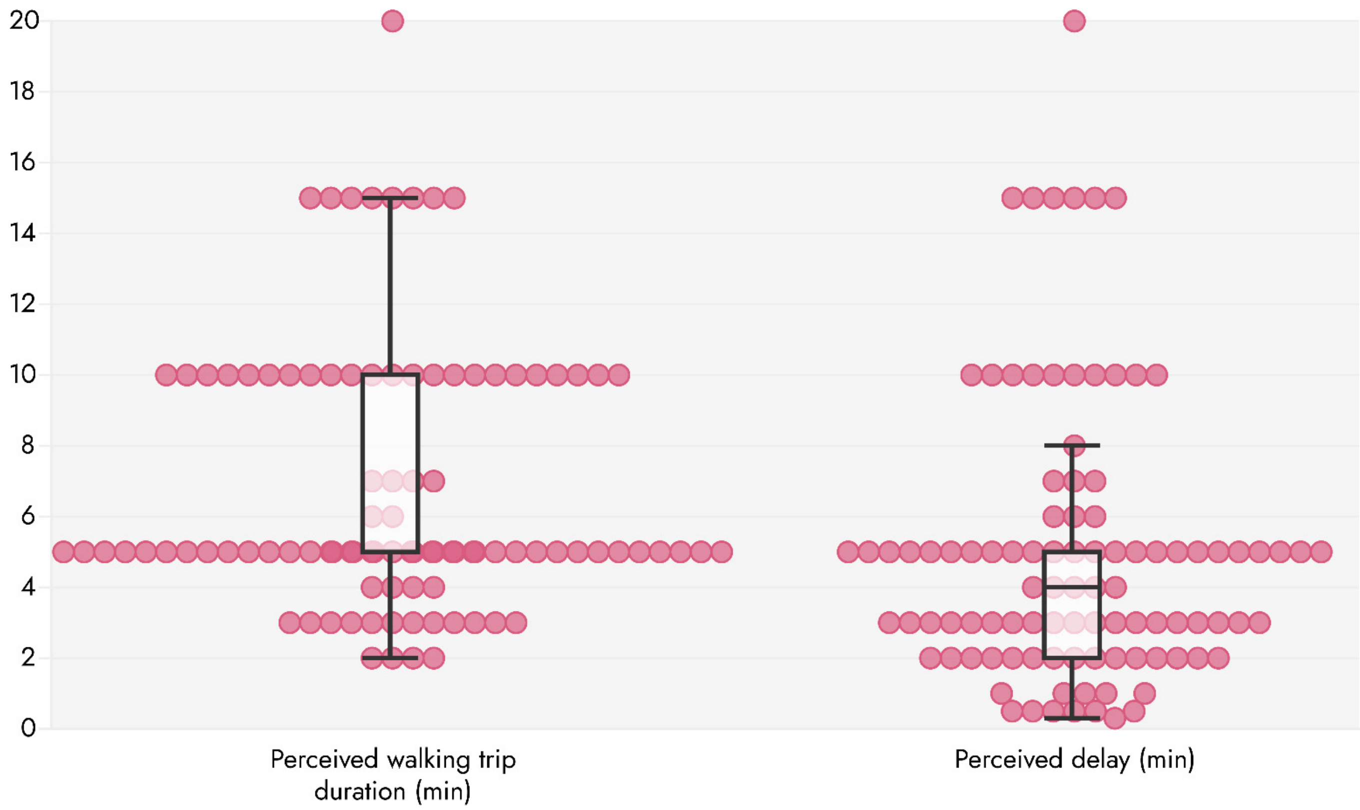

Figure 8. Beeswarm plot of the two examined variables.

As far as the employment status is concerned, no statistically significant differences were pointed out by the One-Way ANOVA test (F(6.93) = 1.645, $p > 0.05$) on the perceived walking trip duration among the various types (e.g., students, employees). On the contrary, statistically significant differences are highlighted in the perceived delay (F(6.93) = 2.524, $p < 0.05$), with students being those experiencing the less time delay, probably due to lower awareness level of road safety rules as well as their increased physical ability to cross the roads faster. The mean values of the perceived walking trip duration and the perceived delay for the different types of employment status are presented in Figure 9.

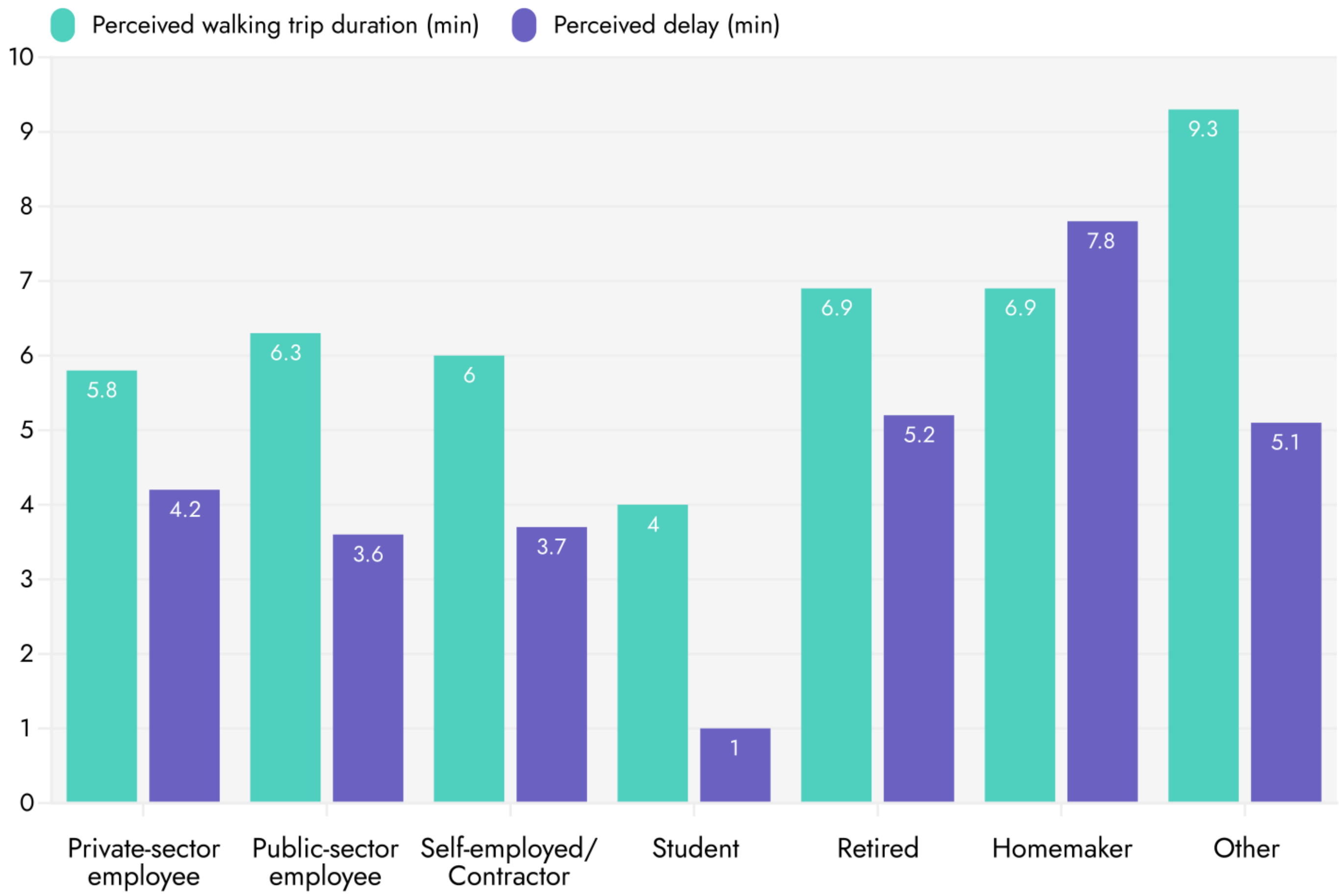

Figure 9. Bar chart illustrating the mean values of the perceived walking trip duration and the perceived delay for the different types of employment status.

Regarding the impacts of the barrier effect as experienced by the different genders, the perceptions and the mobility behaviour of men and women were thoroughly examined through a number of inferential statistics tests. More specifically, an independent samples t-test was performed to compare the delay experienced by men and women. The results (F(87.679) = −2.861, $p < 0.01$) suggest that a statistically significant difference exists between the two genders, with a mean perceived delay of 3.9 min for men and 6.2 min for women. The violin plots illustrating the distribution and the five-number summary (as in box plots) of the delay perceived by men and women are presented in Figure 10.

Figure 10. Violin plots of the delay perceived by men and women.

In line with the above, the willingness of men and women to adapt their trip destination to avoid crossing the two roads was examined by conducting a chi-square test. As indicated by the results ($\chi^2(2) = 11.569$, $p < 0.05$), a significant difference is found between men and women, with only 35% of men being willing to change their trip compared to 65% of women.

In this context, the impact of the barrier effect on the mobility patterns of men and women was further analysed in terms of walking trip cancellation. Based on the results, even though the great majority of both men (96%) and women (98%) agree that crossing the two national roads is somewhat risky or very risky, a gender differentiation was highlighted using the chi-square test ($\chi^2(1) = 6.152$, $p < 0.05$). Thus, a great share of women (45%) stated that they had cancelled a trip in the past, whereas the respective percentage for men is only 22%. The distribution of men's and women's responses regarding the two variables described above is presented in Figure 11.

Finally, concerning the critical interventions that could be implemented to mitigate the barrier effect, apart from the construction of a ring road, which was proposed by the vast majority of the respondents (86%), six (6) additional measures highlighted in the literature were also evaluated in the case of Dispilio, i.e., (a) installation of traffic signals; (b) construction of a pedestrian overpass; (c) construction of a pedestrian underpass; (d) installation of regularly located pedestrian crossings; (e) installation of speed cushions; and (f) strengthening of traffic enforcement. These measures are illustrated as a word cloud in Figure 12 based on their popularity among the survey participants, i.e., the size of each measure is proportional to its frequency. According to the results, the strategic planning to mitigate the barrier effect should primarily focus on installing traffic signals, constructing a pedestrian overpass and introducing regularly located pedestrian crossings along the road axes.

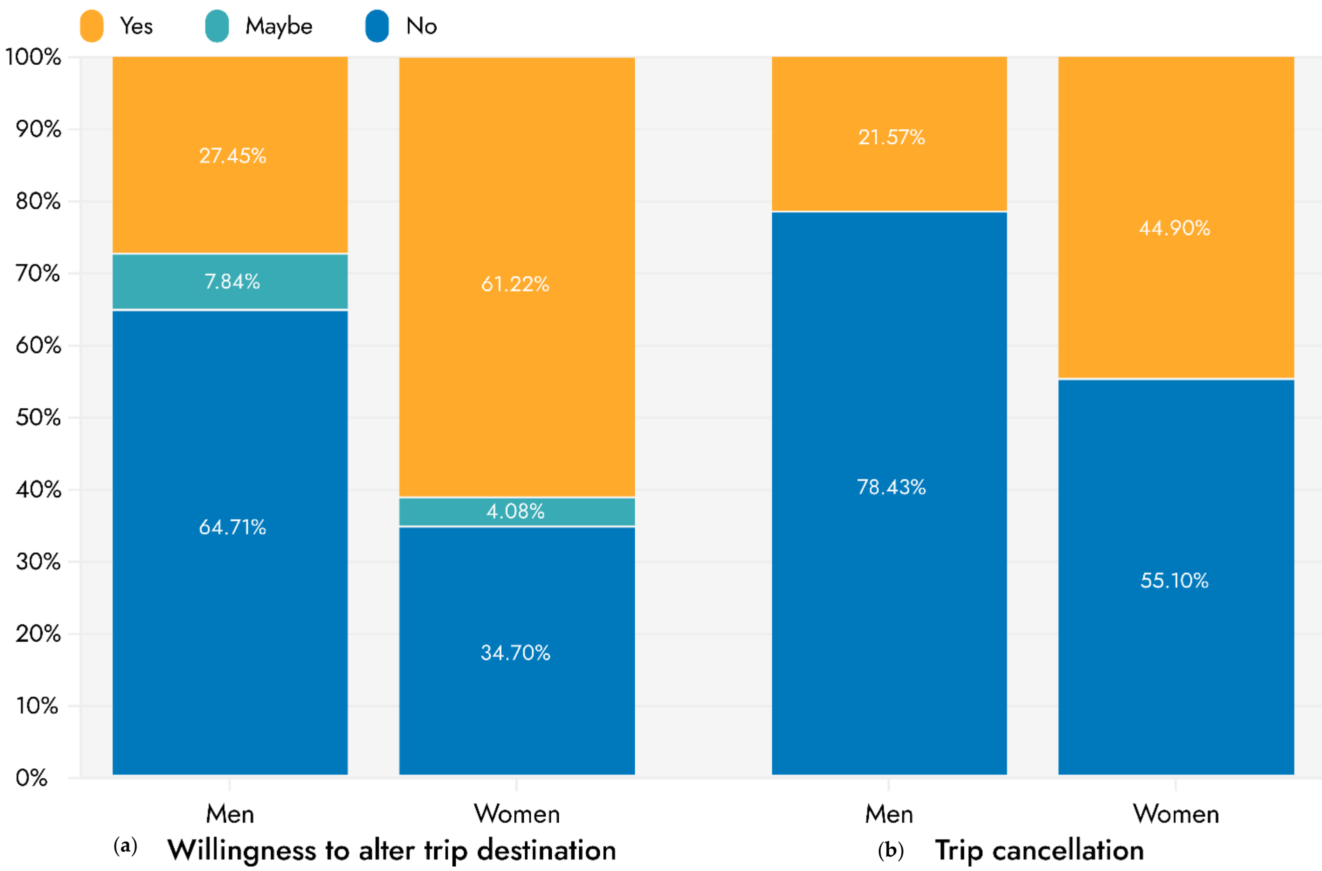

Figure 11. Bar chart presenting men's and women's responses regarding (**a**) the willingness to alter trip destination and (**b**) trip cancellation.

Figure 12. Word cloud illustrating the popularity of six (6) critical mitigating measures.

5. Conclusions

Recognising its multiple adverse effects, a growing number of studies during the last few years have focused on the phenomenon known as the barrier effect or community severance. The barrier effect is typically the result of various static, dynamic or psychological barriers found in the built environment and, based on numerous studies, is considered to bring about a chain of direct and indirect detrimental impacts on vulnerable road users as well as the local communities.

Despite the great evidence of the barrier effect's negative impacts, the developed methodological approaches aiming to evaluate this phenomenon and the case studies conducted to further understand it are rather limited. In this context, the current paper presented a comprehensive methodological approach to assess the actual and perceived dimensions of the barrier effect and subsequently implemented it in a small rural settlement in Greece. To this end, the methodological approach described in this paper utilised a suite of three different tools, i.e., the well-established landscape fragmentation indicator "effective mesh size", the robust accessibility indicator "extra travel distance", and the conduction of a revealed preference survey.

The implementation of the presented methodological approach in the settlement of Dispilio highlighted both in an actual and a perceived manner that the two national roads passing through it act as traffic barriers. More specifically, based on the findings presented in this paper, the study area is severely fragmented into three patches/zones, with their O-D connections, in most cases, not served unless crossing the two main roads. As a result of the presence of traffic barriers, the total distance between all origins and destinations is a quarter longer than the respective on a similar yet barrier-free network. As far as the revealed preference survey is concerned, the descriptive and inferential statistics performed to analyse the questionnaire survey data underlined the main perceived impacts of the barrier effect. More explicitly, the average perceived duration was approximately 6.9 min, while the average perceived delay experienced due to the two national roads was almost 5.0 min. Focusing on the latter, statistically significant differences were highlighted, with men and students perceiving less time delay. As regards the perceptions of the two genders, while the great majority of both men and women agreed that crossing the two national roads is risky or very risky, a significant difference was underlined concerning their willingness to alter trip destination, with only 35% of men accepting to change their trip compared to 65% of women. Similarly, a high share of women (45%) stated that they had cancelled a trip in the past, whereas the respective percentage for men was only 22%.

This paper contributes to the existing literature mainly in two ways. First, based on the authors' best knowledge, this is the first study in this field that combines the tools mentioned above and, in particular, considers the effective mesh size as a valuable and meaningful measure of the barrier effect. Second, contrary to the vast majority of the literature focusing on urban areas, the current paper examined the barrier effect on a small rural settlement developed along two major road axes that, despite initially contributing to its economic growth and openness, ended up hindering movements on the local scale.

In conclusion, the research presented in this paper, including the proposed comprehensive, easy-to-implement methodological approach and the findings of the pilot implementation, could contribute to a better understanding and assessment of the barrier effect and, thus, more targeted transport policies.

6. Limitations of the Study and Suggestions for Further Research

Considering that nearly no study is entirely free of limitations, the research presented in this paper has some shortcomings that could be addressed in further research. In this context, this study's main shortcoming refers to the pilot implementation and, specifically, to the size of the revealed preference survey sample collected. Thus, despite the inherent difficulty in gathering an extensive sample from a small population, a larger sample size, reaching approximately 260 valid responses, would be preferable as it could provide more reliable information. However, given the case-specific nature of the above limitation, it should be noted that the credibility and inferencing ability regarding the barrier effect of the overall developed methodological approach is not in question. As part of future research, an enhanced evaluation of the barrier effect, mainly focusing on the affected population's socio-economic characteristics, could also further highlight valuable findings. Finally, implementing the presented methodological approach in multiple other cases is highly suggested for further underlining its validity and usability.

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