Peer-reviewed version available at *Sustainability* **2017**, *9*, , 883; doi:10.3390/su9060883

Article

Walking across Rural-Urban Fringe: The Hindering Effect of Intersections

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Abstract: The study investigates the influence of road intersections on pedestrian accessibility in urban-rural fringe areas. An evaluation method to support planners and decision makers in the classification of crossing areas according to their effect on walking and in the prioritization of improvement interventions is proposed. In these peripheral parts of towns, pedestrians are almost ignored and people depend on car use for any necessity. Initiatives to improve livability can include the design of walkable friendly environments aiming at offering potential users good levels of security, comfort and convenience when walking to destinations. These spatial requirements have to be provided along road segments and even more on crossing areas which represent sensitive points of the entire connection system with a hindering influence on people's propensity to walk. Starting with spatial basic interventions aiming at enhancing the continuity, safety and quality of pedestrian paths it is possible to reduce the physical and perceptual distance which separates fringe contexts from the rest of the city leading to a progressive integration of urban functions.

Keywords: rural-urban fringe; walkability; road intersections; decision support methods; Electre Tri

1. Introduction

Rural contexts are acquiring great attention in urban planning because of their advancing incorporation in urban systems in terms of spatial continuity of settlements, presence of important urban functions and services, as well as in terms of integration of rural lands in everyday urban practices (). This is particularly evident in locations at the edges of settlements, where rural and urban dimensions (town and country) overlap and often clash. These areas, commonly known as urban-rural fringe, are characterized by low-density residential settlements, prevalence of single-use zoning and day-to-day activities widely separated with increased reliance on the private automobile for transportation. The proximity to built-up areas together with the multiplicity of human activities and services allocated in the fringe lead to very intense crossing flows of energy and matter: every day many people traverse edge areas for living and working. As transport infrastructures of various type extensively pass over these environments they are one of the most inter-linked and frequented areas of urban realm. In many cases, functions are separated by traffic congested roads that create spatial barriers. This entails spatial fragmentation and limits the possibilities for people to easy walk to the variety of activities offered by the fringe.

Non-motorized transport modes are less practiced because of long, uncomfortable, unpleasant distances to travel, and car use prevails.

Compared to rural settings, urban-rural fringe results an environment more conducive to walking as it does not present too high commuting distances , poor facilities and infrastructures, while compared with dense urban fabric fringe areas it offers wider open spaces, ecological and cultural landscape elements which attract people for leisure and promote active behaviors and healthy lifestyle. The nearby landscape amenities provide unique opportunities for walking and cycling as well as for social intersections. Collins et al. [1] observed that young people who live in urban fringe use to stroll the countryside in their free time more than their peers from rural and urban settings. The fragmented condition of urban fringe areas due to their incongruous mix of land uses and functions makes essential to activate recovering processes with which to lead a progressive integration of these areas in the urban system by establishing new synergies between its multiple constitutive components.

One possibility to improve the quality of life in the urban-rural fringe is to increase walkability.

Scholars recognized walkability as an effective indicator of the quality of both urban space and people's life. It is a spatial requisite of built environment which contributes to livability and which enables people to effectively use and benefit urban opportunities. The possibility for people with different motility [2] (ages, gender, residential location, socioeconomic status, personal abilities, …) to reach independently valuable destinations and places represents an important achievement with respect to their right to the city and citizenship. Such a condition becomes fundamental for people living in urban-rural- areas on the periphery of towns and which suffer for spatial and social marginalization.

Hence the investigation of environmental factors correlates to walk in urban-rural fringe offers useful insights and information on how to extend urban quality in peripheral settings affected by poor livability. Moreover, studying how best to measure and assess the walkability of built environment represents an important operational support for both planners and decision makers involved in addressing policies and strategies able to help urban-rural fringe areas fulfill their considerable potential of sustainability.

To be more precise, making urban-rural fringe walkable corresponds to improve the spatial quality of a living environment at the moment perceived as physically uncomfortable and emotionally unpleasant especially for pedestrians. A first intervention to this purpose concerns spatial connectivity. The creation of continuous, fluid itineraries that give access to different destinations and able to accommodate different kinds of mobility instead of the private car only, is a way to make urban-rural fringes more livable. Connected, well-maintained pedestrian networks allow people to safely and conveniently perform local activities (both urban and agricultural productions) reaching basic facilities (commercial , offices, schools, businesses, leisure, …) and collective spaces (green open spaces, public amenities) thus providing opportunities of social engagement and economical outcomes.

With respect to environmental sustainability, an increasing walkability can produce positive impacts on community behaviors and lifestyles. Cross-disciplinary studies [3] evidenced that a walkable environment encourages healthy lifestyle with benefits for both people and the environment: walking is an easy and inexpensive form of physical activity, with consequent health benefits for people of all ages. In addition, the habitual practice of walking and cycling contributes to reduce car trips and thereby decreases harmful auto emissions [4].

However, the major problem of urban-rural fringe does not relate to the lack of linking elements, considered the number and variety of roads crossing the area. It is rather the quality of accessibility, especially the experience of pedestrians, to be reduced and damaged due to the diffused lack of spatial attributes and requirements of built environment that encourage walking. Among spatial factors affecting people's choice to walk we focus on the role of road intersections and their hindering effect on pedestrian accessibility. Intersections, by their very nature, are locations with a considerable potential for conflict between different road users. They are topological interruptions of a pathway which, depending on geometric and operational characteristics, represent tangible interferences towards the final destination of a trip. They caused

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time delay, expose pedestrian to traffic risk, etc. In other words they can be considered as impedance factor of walkability.

Starting from these considerations, we propose an analytical and assessment method to measure the difficulty caused by intersections on pedestrian stream; an evaluation method useful to orient policy makers and to suggest priority of intervention strategies. In the first part of the paper we analyze the state of the art of the methods aimed to evaluate the conduciveness to walking of road intersections. Then, we present our research method, the survey design and the evaluation model. More precisely, the description of the evaluation model is structured as follows: (1) detection of the most relevant factors of intersections that affect the attitude of people to walk by mean of a multiple linear regression model; (2) definition of an evaluation rating model using Electre TRI method [5,6]; (3) application of the model to a case study and comparison of the results with the subjective perception of individuals. Finally, we define a model useful to identify needs, prioritize actions and define strategies of intervention in respect to functional and perceptive elements that foster the walkability and the experience across urban rural fringes.

2. Incorporation of the qualities of road intersections in walkability measures: state of the art

In the last decades urban and transport studies deepen explored built-environment determinants of walking, focusing on the attributes of roads (the edges of the network) and their surrounding environment [7]. Minor attention has been given to intersections (the nodes of the network) as hindering factors of walking, despite pedestrian path continuity represents one of the main spatial condition that affect the propensity of people to walk. Most studies on urban space conduciveness to walk consider road intersections merely in terms of density, according to the principle that high numbers of urban intersections per unit area correspond to easier pedestrian mobility, various alternatives of path and higher number of walking trips. No mention was given to geometric and operational characteristics of road intersections except for typological features such as the number of streets converging in each node. We refer to the spatial connectivity indicators included in the most widely measurement methods of urban walkability [8,9,10] and expressed as node number and type (commonly number of legs joining in each node) within large spatial units (km^2, block, neighborhood). As a result, the incorporation of spatial connectivity indicators into composite indices of walkability lead to incongruous scales of observation of addictive terms, with terms related to street edges qualities derived from detailed micro-scale data analysis and computations and factors related to nodes based on a rougher level of scrutiny.

Our research assigns importance to the micro-level analysis of intersections in the overall evaluation of urban walkability as the spatial and operational characteristics of crossing area are truly hindering or conducive factors that affect the practicability of paths by pedestrians.

Pedestrian level of service measures and assessments (PLOS) represent the field of studies that deals more deeply with the factors of the built environment responsible of the hindering effect of road intersections on pedestrian accessibility. PLOS introduced by Fruin [11] and later internalized by TRB's HCM [12] is a measure of the operational quality of pedestrian facilities based on fine-grained analysis of physical space and traffic flows. Researchers broadly employed this method for enrich the set of factors affecting pedestrian behavior both along sidewalks and at crossings. Traffic safety concerns, comfort requirements and pedestrian delay resulted key performance indicators of walking impedance of crossings [13]. Most recent studies combine physical and operational variables with pedestrian's perceptions of safety and comfort with the latter measured by collecting walkers movement and perception data through direct observations by mean of surveys and videos. The study of Sisiopiku and Akin [14] sought pedestrian perceptions toward various signalized and unsignalized intersections and recognized the distance of the crosswalk to desired destinations as the most influential factor in making a decision to cross. Basile et al. [15] used the AHP method to assess the safety level of pedestrians at regulated and not regulated crossings. A composite index for crossing safety and some specific indexes for main aspects included in the assessment allowed to rank crossings on the basis of their spatial characteristics and address intervention priorities highlighting the issues that need to be improved. Absence of pedestrian

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refuge islands, improper traffic light timing, on street car parking blocking visibility and accessibility problems due to obstacles on pedestrian crossing emerged as factors influencing most pedestrian safety.

But, the majority of studies resort to field-calibrated statistical models based on multiple linear regression equations, logit and probit models. Petritsch et al. [16] provides a measure of the pedestrian's perspective on how well an intersection's geometric and operational characteristics meets his or her needs. The formulated equation is based on three terms: (1) perceived conflicts which refer to turning traffic (right-turn-on-red vehicles and permitted-left turn); (2) perceived exposure which refers to volume and speed of perpendicular traffic and number of lanes to cross, and (3) pedestrian delay. By comparing objective data of crossing areas (geometric, operational and traffic characteristics) with pedestrian perception of safety and comfort Muraleetharan et al. [17] developed a LOS estimation method to rank intersections according to their performances with respect to walking. Factors such as space at corner, crossing facilities, turning vehicles, delay at signals, and pedestrian-bicycle interaction were identified as the primary factors affecting pedestrian LOS at intersections. A similar model based on multiple linear regression analysis was proposed by Bian, Lu and Zhao [18] for un-signalized intersections and revealed conflicting traffic of motor vehicles and bicycles and crossing distance as relevant factors to consider in planning. Hubbard et al. [19] used a binary logit model to study factors that affect the likelihood of a pedestrian being compromised when approaching intersections and recognized "traffic turning right on green" as the most influencing element, which resulted even stronger on crosswalks located in suburban areas.

According to this frame the barrier effect caused by traffic (motorized and nonmotorized) and the crossing distance represent the principal obstacles perceived by pedestrian at intersections. As a consequence the spatial configuration of crossing areas and their equipment become fundamental requirements for planners in order to encourage walking.

3. Methodological approach

As previously said, in urban-rural fringe areas several environmental attributes discourage on foot trips with intersections representing one important hindering element due to their geometry and operational characteristics. With the aim of making these contexts more livable, planners and decision-makers need to be supported by methods that effectively address the identification and evaluation of interventions that encourage or detract from walking.

For this purpose an analysis and a rating method of road intersections based on their hindering or facilitating effect on walking is proposed and tested on a sample of street crossings in the city of Alghero, Sardinia.

The method consist of two different phases: first a field survey in which objective measures of spatial and operational characteristics of crossings that influence walkability were collected and compared to subjective judgments expressed by pedestrians with regard to the same sample of intersections; second an evaluation procedure by mean of the ELECTRE TRI rating method [5,6] which classified intersections based on their conduciveness to walking.

In the first phase a linear regression analysis was used to compare objective and subjective information of the analyzed crossings and led to identify the most important factors influencing pedestrian accessibility and their weights that is their relative importance in the measure of walkability. In the second part of the study we developed a method to compare and classify intersections on the basis of their greater or lesser incidence on walkability. The resulting rating makes it possible to identify those crossings with priority needs with regard to walking conditions. The variety and diversity of attributes considered in the study suggested the use of a multi-criteria rating evaluative method. More precisely, we adopted the ELECTRE TRI rating method because of its ease of implementation and of communication results. These qualities make this rating method particularly useful and favorable in integrated transport and land use planning processes aiming at formulate policies and actions that promote walking.

The study we propose illustrates an operational method able to address planning and design

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activity through a more aware knowledge about the qualities of road intersections that affect safety, comfort and pleasantness of pedestrian experience of urban space. It also offers a support tool for decision makers in the evaluation and prioritization of interventions.

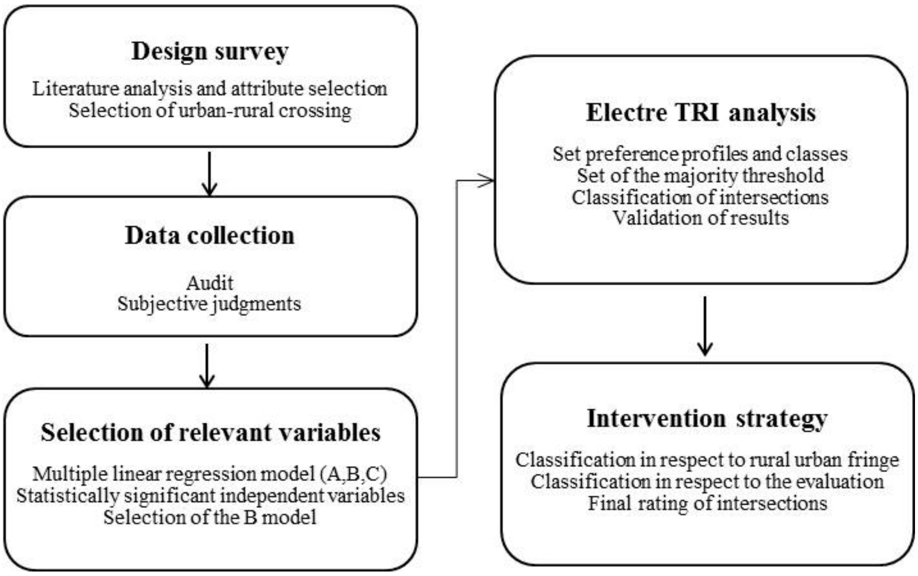

Figure 1. Methodological framework.

4. Evaluation of road intersections in the city of Alghero

4.1. Experimental design

A contingent field survey was conducted in 181 crossings of 45 intersections (Fig. 1) in the city of Alghero (Italy). Intersections were selected evenly distributed in the urban fabric and not only located in fringe areas with the aim of having an heterogeneous sample as representative as possible of the experience of urban space made by pedestrians. Selection took into account strategic location with respect to urban facilities at local and city level, to the spatial and operational characteristics of approaching road (functional classification, number of lanes, crossing distances,…). This entails differences in the configuration of crossing areas, surrounding land-uses, vehicular and pedestrian volumes and behaviors.

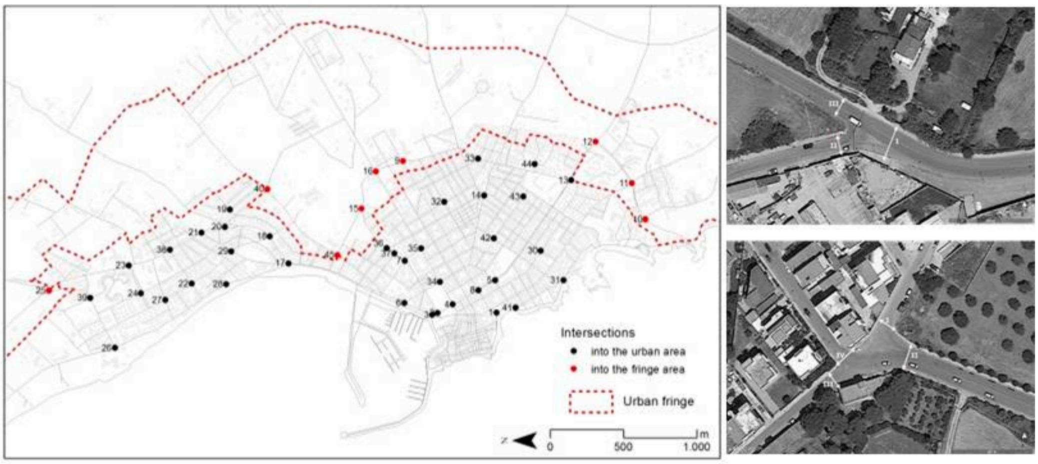

Figure 1. The overall 45 surveyed intersections in the city of Alghero (right), and detail of the subdivision into crossing lanes (for intersection 15 and 40).

With the support of a group of postgraduate students a field survey was conducted at each

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selected site. Two separate measures were collected for each crossing in 2 different moments of the day (morning and evening): (1) a detailed audit based on 24 micro-scale attributes summarized in Table 1, and (2) a synthetic subjective judgment of the "cross-ability" based on safety and comfort requirements perceived by pedestrians. For each intersection specific attention was paid to keep separate observers who collected data and those who expressed judgments.

The direct field survey of nodes was conducted taking direct measurements of crossing physical characteristics and with the support of videos for the count of vehicular and pedestrian volumes. For practical purposes, we subdivided each intersection into individual lane crossings a pedestrian can walk in order to consider all the routing alternatives (see Figure 1, right). Each individual crossing was then analyzed according to the variables in Table1.

With regard to the objective variables used in the audit they consist of: (1) spatial configuration of crosswalks (geometry and dimensions); (2) obstacles to visibility with information on position, size, consistency, permanence of obstructing elements; and (3) practices of use (count of motorized and non-motorised flows, vehicle speeds and waiting time to cross).

Table 1. Attributes of crossings.

	Attributes (variables)	**Scale levels**
X1	**Carriageway width (C_w)**	*(continuous)*
X2	**Sidewalk width (left & right)**	*(continuous)*
X3	**Number of vehicular lanes**	*(continuous)*
X4	**One-way traffic**	*1 Yes, 0 No*
X5	**Bicycle lanes**	*1 Yes, 0 No*
X6	**Traffic light**	*1 Yes, 0 No*
X7	**Couple of curb cut**	*1 Yes, 0 No*
X8	**Elevated sidewalk**	*1 Yes, 0 No*
X9	**Crossing island (median)**	*1 Yes, 0 No*
X10	**Physical elements directing pedestrian movements (left & right)**	*1 Yes, 0 No*
X11	**Sidewalk extensions**	*2 Yes, both side, 1 Yes, one side, 0 No*
X12	**Crosswalks condition**	*0 Absent, 1 Yes, faded, 2 Yes, well-defined*
X13	**Space at corner (left & right)**	*3 Wide (4-6 or more people await and comfortable passage)* *2 Medium (2-3 people await and enough passage space)* *1 Limited (1 person await and no passage space)*
X14	**Position of zebra crossing**	*2 In-line (less that 10 steps from the street corner),* *1 Lateral (more that 10 steps from the street corner),* *0 Absent*
X20	**Bicycle flow rate**	*(continuous) [frequency in 10 min]*
X21	**Car flow rate**	*(continuous) [frequency in 10 min]*
X22	**Bus and truck flow rate**	*(continuous) [frequency in 10 min]*
X23	**Motorcycle and scooter flow rate**	*(continuous) [frequency in 10 min]*
X24	**Pedestrian flow rate**	*(continuous) [frequency in 10 min]*
X25	**Mean vehicle speed**	*(continuous) [mean value in km/h]*
X2	**Waiting time at intersection**	*(continuous) [mean value in seconds]*

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X30	**Presence of obstacles on the curb**	*1 Yes (presence of obstacles in street and/or on curb),* *No (absence of obstacles)*
X31	**Presence of "inner"obstacles**	*1 Yes (presence of obstacles further back than 2 meter from the curb),* *No (absence of obstacles)*
X32	**"Summary level" of obstacles**	*(continuous)* *Presences + Height + Transparency + Permanence*

With regard to the synthetic subjective evaluation of the conduciveness to walk of crossings, auditors were asked to cross each crossing composing the intersection and to express an overall evaluative judgment about the pedestrian quality according to an ordinal qualitative scale, from 1 ("insufficient") to 4 ("Very good"). Table 2 reported the characterization of each evaluation degree defined on the basis of the spatial configuration and of the safety and comfort perceived while crossing.

Table 2. - Synthetic judgments on pedestrian friendliness of road crossings.

Synthetic judgment		**Description**
4	**Very good**	*comfortable crossing, with a good level of safety; the road is enough easy to cross and it takes a short time, waiting area is wide enough and traffic is rather safe.*
3	**Good**	*crossing with medium level of comfort and safety; crossing the road is not that difficult and takes medium waiting time, space for pedestrians is enough comfortable in dimensions and quality, and pedestrian is averagely safe from traffic paying proper attention.*
2	**Sufficient**	*the crossing meets minimum standards of comfort and safety; some characteristics make walking difficult, the waiting space is limited and to cross from curb to curb takes long time, traffic can be dangerous and requires to keep proper attention.*
1	**Insufficient**	*the crossing is completely uncomfortable and dangerous; it is inconvenient to cross and it requires to wait very long time. The waiting space is inadequate to hold people, traffic is very dangerous and makes almost impossible to pass from curb to curb.*

4.2. Identification of significant attributes

The set of data collected by field observation and survey was then analyzed. A preliminary frequency analysis of perceived judgment of crossings (Figure 2) showed a general positive perception of intersection quality by pedestrian's point of view.

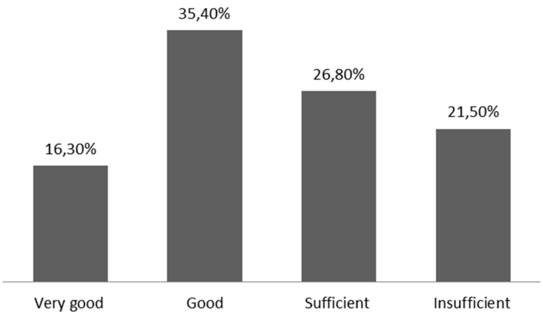

Figure 3 - Frequency analysis of evaluative judgment of crossings expressed by pedestrians

Audit data were processed to convert left and right side measures into a single variable (i.e.

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minimum sidewalk width) as well as to reduce measurement errors (i.e. average vehicle speed).

Thereafter statistical analysis was conducted using multiple linear regressions with two main purposes: (1) to identify the attributes which influence most the conduciveness to walk of intersections and (2) to explore the correlation between perceived evaluations of pedestrian quality of crossing (dependent variable) and the attributes of crossings (independent variables).

Thus, a first analysis identified statistically significant independent variables. Different regression models developed are reported in Table 3. Starting from Model A, which yielded R-squared=0.72, and using the ≥0.01 level significant variables, we obtained Model B (R-squared=0.66) composed of significant variables only: (X1) carriageway width; (X6) traffic light; (X7) couple of curb cut, (X9) crossing island; (X11) sidewalk extensions; (X12) crosswalks condition; (X14) position of crosswalks; (X20) bicycles flow rate, (X21) car flow rate and (X24) pedestrian flow rate. The sign of coefficients of each variable, confirms the intuitive idea that attributes X1, X20 and X21 have a negative influence on the safety and comfort of crossing, while the other statistically significant variables influence it positively considering that they consist of pedestrian friendly equipments such as medians, sidewalk adjustments and control systems etc. The relative importance of the independent variables investigated by mean of separate univariate linear regression for Model B variables is proposed in Table 4. These results evidenced a strongest individual effect (R-squared>0.10) on variables X6, X7, X12 X14 and X24 which are included in Model C (R-squared=0.59).

Table 3. Multivariate linear regression models.

	Model A (R-squared=0.72)				**Model B** (R-squared=0.66)				**Model C** (R-squared=0.59)			
	Est.	St. err.	p-val.		Est.	St. err.	p-val.		Est.	St. err.	p-val.	
(Incpt.)	0.4491	0.0763	2.5e-08	***	0.4754	0.0404	<2e-16	***	0.3304	0.0229	<2e-16	***
X1	-0.4596	0.1573	0.0040	*	-0.3533	0.1393	0.0121	*				
X2.1	-0.1312	0.0750	0.0825									
X2.2	-0.0653	0.1179	0.5804									
X2.3	0.2364	0.1545	0.1282									
X3	0.0983	0.1288	0.4465									
X4	-0.0167	0.0387	0.6660									
X5	-0.0089	0.0485	0.8539									
X6	0.1582	0.0469	0.0010	***	0.2083	0.0353	2.1e-08	***	0.1857	0.0379	2.2e-06	***
X7	0.0531	0.0270	0.0508	.	0.0800	0.0266	0.0030	**	0.0970	0.0279	0.0006	***
X8	NA	NA	NA									
X9	0.1076	0.0405	0.0087	**	0.1189	0.0371	0.0016	**				
X10.1	-0.0062	0.0675	0.9266									

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X10.2	-0.0315	0.0655	0.6308									
X11	0.2089	0.0805	0.0104	*	0.2055	0.0698	0.0037	**				
X12	0.1580	0.0437	0.0004	***	0.1340	0.0405	0.0011	**	0.1626	0.0435	0.0002	***
X13.1	0.0969	0.0671	0.1507									
X13.2	0.0365	0.0774	0.6234									
X13.3	0.0204	0.0973	0.8344									
X14	0.1571	0.0434	0.0004	***	0.1471	0.0400	0.0003	***	0.1500	0.0426	0.0005	***
X20	-0.2098	0.0806	0.0101	*	-0.1739	0.0675	0.0108	*				
X21	-0.2014	0.0931	0.0322	*	-0.1394	0.0515	0.0075	**				
X22	0.0396	0.1091	0.7173									
X23	0.0125	0.0789	0.8739									
X24	0.3292	0.0928	0.0005	***	0.4382	0.0782	8.3e-08	***	0.4156	0.0787	3.8e-07	***
X25.1	0.2162	0.2312	0.3513									
X25.2	-0.2502	0.2351	0.2890									
X26	0.0944	0.1177	0.4239									
X30	0.0815	0.0425	0.0571	.								
X31	0.0378	0.0396	0.3413									
X32	-0.1912	0.0896	0.0345	*								

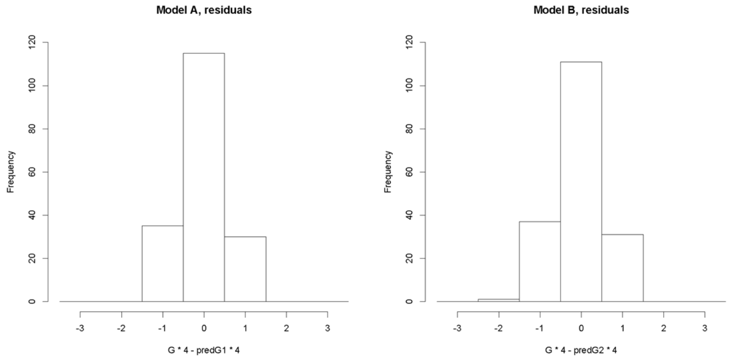
Table 4. Univariate linear regressions for the most significant independent variables.

	X1	X6	X7	X9	X11	X12	X14	X20	X21	X24
Coef. est.	-0.7461	0.2748	0.2528	0.0209	0.3329	0.3381	0.3564	-0.1329	-0.1120	0.5664
Std. Error	0.1929	0.0506	0.0320	0.0528	0.1061	0.0393	0.0341	0.0969	0.0743	0.1123
p-value	0.0002	1.8e-07	2.7e-13	0.6940	0.0020	3.8e-15	<2e-16	0.1720	0.1330	1.1e-06
(Intercept)	0.7784	0.5898	0.5000	0.6234	0.6134	0.4517	0.4194	0.6538	0.6611	0.5560
(Std. error)	0.0432	0.0185	0.0226	0.0201	0.0186	0.0256	0.0246	0.0272	0.0295	0.0223
(p-value)	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16	<2e-16

R-squared	0.0776	0.1420	0.2599	0.0009	0.0524	0.2941	0.3800	0.0105	0.0126	0.1251

4.3 Accuracy of the model

The comparison between predicted and observed values supports the identification of the model that better represents the "quality value", starting from the spatial audited information. The distribution of residuals (Figure 3) between expressed evaluations and values of the regression models, elected Model A as the best fitting given that it yielded results which are close to the observed values (63.9% of crossing in the correct class, 36.1% in one class off and 0.0% in two classes off). Likewise the precision of Model B is very good as the probability to classify crossing in at most one class off is 99,5%: For both this reason and the lowest number of variables we used Model B for the next stage of the study. For a more a more detailed discussion see [20].



	Residuals					Classification		
	Min	1st Qu.	Median	3rd Qu.	Max	Correct	1 cl. off	2 cl. Off
Mod. A	-1.50	-0.36	-0.05	0.37	1.39	63.89%	36.11%	0.00%
Mod. B	-1.76	-0.39	-0.05	0.37	1.38	61.67%	37.78%	0.56%
Mod. C	-1.54	-0.38	-0.01	0.47	1.66	56.11%	42.78%	1.11%
Mod. D	-1.86	-0.51	-0.11	0.49	2.49	41.67%	57.22%	1.11%

Figure 4. Univariate linear regressions for the most significant independent variables.

4.4 Classification of intersections

4.4.1 Evaluation procedure

In this stage of the study we rank intersections according to their conducive or hindering effect on pedestrians mobility with the final aim to identify critical factors of intersection design and management which limit walking thus setting the stage for subsequent improvement actions, which usually are implemented on the basis of decision priorities.

Therefore the proposed model provides local decision makers a formal method for prioritizing interventions on intersections that will yield benefits in terms of improved pedestrian safety and comfort and increased number of people who decide to walk.

We propose to evaluate road intersection performance toward walking using the ELECTRE TRI method [5,6].

The multidimensional nature of the problem, which encompasses objective attributes and preferences, suggests to use a multicriteria method.

Among the multiple criteria evaluation rating methods, ELECTRE TRI has several properties useful for the aim of the present research: (i) it allows sorting road intersections in ordered prioritizing classes according to their importance on specific criteria; (ii) criteria aggregation is flexible and allows to express the relative weights, clusters of coalitions (majority rule) and eventual vetoes; (iii) it allows a prudential non-compensatory aggregation of information with limited loss of information during consecutive stages of evaluation; (iv) it is a procedure that resembles individual models of judgment; and (v) outcomes are simple to interpret and communicate so that it is an useful support tool for planning and decision making.

For these reasons ELECTRE TRI is a method widely utilized in urban and transport engineering problems. Fancello et al. [21] resort to this method to support decision makers in the definition of intervention priorities to ensure safety conditions on roads. Sousa et al. [22] used Electre Tri to assess sidewalks performance in the sense of their suitability for walking.

4.4.2 A brief reminder of the ELECTRE TRI sorting model

Electre Tri model is a method that assigns alternatives to pre-defined categories. Each alternative an is composed by a group of criteria h1, h2, …, hn that are assigned to one and only performance class.

Generally, when variables are continuous, in the ELECTRE TRI model each class Ck is defined by a limiting profile πk on the criteria. Formally:

$$a \in Ck \Leftrightarrow a \; P \; \pi k \wedge \pi k+1 \; P \; a$$

where P indicates the binary outranking relation meaning "has the same or higher priority than".

Whereas, with discrete variables, such as in our case, each modality is directly assigned to one class.

According to the method each alternative is assigned to one class Ck when there is a "significant coalition" of criteria for which "a has the same or higher priority than πk (concordance principle) and there are no "significant opposition" against this proposition (discordance principle). Formally:

$$a \; P \; \pi k \Leftrightarrow C(a,\pi k) \wedge \neg D(a,\pi k)$$

where:

- C(a, πk) means there is a majority of criteria supporting the proposition that a belongs to C.
- D(a, πk) means there is a strong opposition to the proposition that a belongs to C. This opposition is expressed by veto rules.

$$C(x,y) \Leftrightarrow (\sum wi \, / \sum wj) \geq \gamma$$

$$D(x,y) \Leftrightarrow \exists hi : hi(y)-hi(x)>vi$$

where:

- hi, i=1,...,n are the criteria (the higher the value the higher the priority),
- wi are the coefficients of importance (weights) associated with each criterion,
- hi(x) is the evaluation of x on the criterion hi,
- H(x,y) is the set of criteria for which x has the same or higher evaluation than y, that is, for which hi(x) ≥ hi(y),
- γ is the majority threshold,
- vi is the veto threshold on criterion hi.

4.4.5 Evaluation criteria

For the evaluation of the 45 road intersections we defined three performance classes with regard to pedestrian quality of crossing areas: C1 “Conducive to walk”, C2 “Support walking”, C3 “Obstacle to walk”, each of them responding to the following requirements:

Table 5. Performance classes of crossing pedestrian quality

C1 **“Very good to walk”**	**C2** **“Support walking”**	**C3** **“Obstacle to walk”**
the crossing is very safe and comfortable. Street width is narrow or the traffic flow is regulated by crossing facilities	the crossing is enough safe and comfortable. Street width is medium, with some crossing facilities.	the crossing is not safe nor comfortable. Street width is wide, lacking crossing facilities

Each individual crossing composing the intersection was evaluated on six criteria h1, h2, …, h6 defined on the basis of the spatial and operational attributes which resulted statistically significant in the regression analysis model (Model B paragraph 4.1). The six criteria reflect the performance of the crossing with regard to its conduciveness to walk derived from the respective attributes. Tables 6 and 7 give details on the six criteria utilized.

In particular Table 6 summarizes the variables utilized in the ELECTRE TRI rating model with their relative modalities and weights. According to the results of regression analysis, each variable has a coefficient (β) that can be interpreted as the influence of the variable on the quality level of crossings. Based on this consideration we used the β coefficient values (normalized such that $\sum w=1$) as the weight of each variable in the ELECTRE TRI procedure.

Because of the mutual influence and relationship between variables, we decided to aggregate some variables in the so-called super-indicators, according to the inclusion relation and the Hasse diagram procedure [23]. The Hasse diagram represents all the possible combinations of variables which compose the super-indicator and the relative dominance relation.

According to the logic of partial order approach variables are aggregated into equivalence and indifference classes. Equivalent combination of variables form groups; combination of groups are indifferent. With reference to Figure 4, the two combinations 1YNY and 1YYN are equivalent and form a first group (class of equivalence, dashed line shapes); in the same way combinations 2YYN, 1NNY, 2YNY and 1YNN are equivalent and form a second group. For decision makers committed in the assignment of a super-indicator to a class the two groups are indifferent (class of indifference, continuous line shapes).

Table 6. Crossing variables of statistical model B

Variable / attribute	**Modalities**	**Normalized weight**
X1 Carriageway width (C_w)	1 *if* $C_w < 6$m, 2 *if* $C_w \geq 6$m and Cl < 9m 3 *if* $C_w \geq 9$m	0,176773742
X6 Presence of traffic light	0 No 1 Yes	0,104222956
X7 Couple of curb cut	0 No 1 Yes (both side)	0,04002802
X9 Crossing island (median)	0 No 1 Yes	0,059491644

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X11 Sidewalk extension	0 No 1 Yes (at least one side)	0,102821975
X12 Zebra crossing condition	0 Absent 1 Yes, faded 2 Yes, well-defined	0,067046933
X14 Position of zebra crossing	0 Absent 1 Lateral (more than 10 steps from the street corner) 2 In line (less than 10 steps from the street corner)	0,073601521
X20 Bicycle flow rate	(continuous)	0,087010908
X21 Car flow rate	(continuous)	0,069748824
X24 Pedestrian flow rate	(continuous)	0,219253477

According to this rationale, we define two groups of super-indicators: one is composed of the combination of variables (X1) carriageway width (converted into number of lanes), (X6) presence of traffic light, (X9) presence of the crossing island and (X11) sidewalk extension; the second group is composed of the variables (X12) zebra crossing condition and (X14) zebra crossing position.

Each possible alternative to be classified is represented by a sequence of four values one for each variable, for example, the 3YNY alternative indicates an intersection with carriageway width ≥ 9m (means 3 or more lanes), with traffic light, no crossing island, with sidewalk extension.

We assigned the possible combinations of variables X1, X6 X9 e X11 to three classes of pedestrian quality according to relations of inclusion represented in the diagram in Figure 4. As can be expected, there is a nonlinear relationship between the variables included in a group. For instance, the carriageway width is not so important if the traffic light is present. Even more, the sidewalk extension and the crossing island are not necessary if the number of lanes is less than 2.

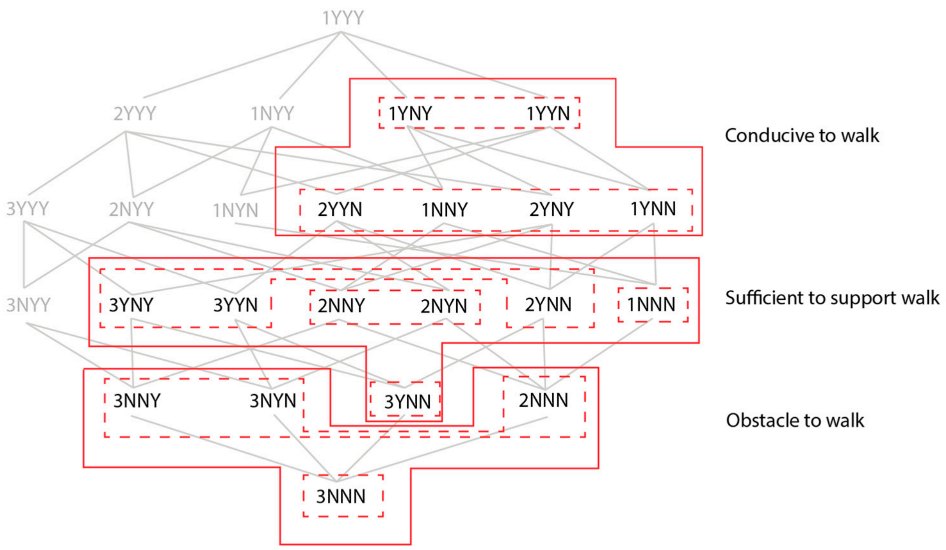

Figure 5. Combination of crossing variables (super-indicator 1).

Moreover, Figure 4 shows that each possible combination is associated with one and only class (e.g. 1YNY is indifferent to 2YNY or to 1YNN and are all classified as C1) and that super-indicators in C1 "conducive to walk" are preferred to those in C2 "support walk" which in turn are preferred to super-indicators in C3 "obstacle to walk". Formally:

1YNY ≡ 1YYN ≽ 2YNY ≡ 2YYN ≡ 1NNY ≡ 1YNN > (class C1)
⊚ 3YNY ≡ 3YYN ≡ 2YNN ≽ 2NNY ≡ 2NYN ≡ 1NNN ≽ 3YNN > (class C2)
⊚ 3NNY ≡ 3NYN ≡ 2NNN ⊚ 3NNN (class C3)

where:
≡ means "equal in value to", ⊚ means "at least as good as", ⊚ means "better than".

In other words, combinations of variables that are "equal" or "at least as good as" are assigned to the same class, even though some of them can be objectively better than the others (e.g. "1YNY ⊚ 2YNY" means that the second alternative is considered at least as good as the first one, even though the first one is better. Thus, both are classified in C1).

In the case of "better than", the alternatives belong to different classes (e.g. "1YNN ⊚ 3YNY" means that the first alternative is better than the second one, thus they are assigned to different classes).

At the same way, the super-indicator composed by zebra crossing condition and position belongs to C1 "conducive to walk" if zebra crossing is in-line and well-defined, it is classified as C2" support walk" if the zebra crossing is lateral and at least faded or if it is in-line and at least faded and finally it is assigned to C3 "obstacle to walk" if zebra crossing is absent.

Weights of each super indicator are defined by the sum of the normalized weights of each variable composing the super-indicator ($w_{si}=\sum w_i$).

The Electre Tri model is therefore composed of six criteria, two of which are super-indicators.

Table 7 summarized the six criteria, relative weights and conditions of inclusion in the three classes.

Table 7. ELECTRE TRI model

W	Criteria	C^3 "Obstacle to walk"	C^2 "Support walk"	C^1 "Very good to walk"
44,33%	X1+X6+X9+X11	3NNY, 3NYN, 2NNN, 3NNN	3YNY, 3YSN, 2YNN, 2NNY, 2NYN, 1NNN, 3YNN	1YNY, 1YSN, 2YNY, 2YYN, 1NNY, 1YNN
14,06%	X12+X14	00	12, 22, 21	11
4,00%	X7	No	Yes	Yes
8,70%	X20	> 18	18 ≤ x < 10,5	≤ 10,5
6,97%	X21	> 549	549 ≤ x < 285	≤ 285
21,93%	X24	> 27	27 ≤ x < 60,75	≤ 60,75

In order to classify the alternatives in respect of specific coalitions of indicators we fixed the majority threshold equal to 51%. In this way none of the super-indicators have an absolute majority and the class is reached only with a coalition of the first (super)indicator (X1+X6+X9+X11) with at least one of the others (excluded X7), or with the combination of the four indicators X12+X14, X20, X24 and X21. Based on this outcome of the classification the indicator X7 does not influence the decision process. This result confirms the low weight reached by the variable in the statistical model (β=0.08 in model B).

4.4.5 Results and accuracy of the classification model

According to the classification model we obtained 5 crossing in the first class C1 "Conducive to walk", 104 in the second C2 "Support walk" and 71 in the last class C3 "Obstacle to walk". Among the 180 crossings analysed 43 (24%) of them are located within rural urban fringe areas, 27 of which fall in the first class C1 , and the remaining 16 in the second class C2. As presumable, none results conducive to walk (class C3).

In order to test if our rating model is able to express a classification in concordance with the perceived judgments of crossing quality expressed by pedestrians we compared the latter with the results of the Electre Tri model. For this purpose we assumed that crossings classified "insufficient" represent "obstacles to walking", those judged "sufficient" and "good" "support walking" and those evaluated "very good" correspond to crossings "conducive to walk". Then we compared the results of the model with the surveyed preferences. The output is the confusion matrix in Table 8.

Table 8. Confusion matrix of comparison between predicted and observed rating of intersections.

		Predicted			
		C^1	C^2	C^3	SENSITIVITY (producer's concordance)
Observed	C^1	28	40	3	39%
	C^2	5	74	25	71%
	C^3	0	0	5	100%
	PRECISION (user's concordance)	85%	65%	15%	**59%**

The overall concordance (i.e. the ratio between the diagonal and all the classification) indicates the precision of the ELECTRE TRI model in the classification of the alternatives (59%). The producer's concordance (sensitivity) is the ratio between the number of correct classification in X and the number of actual value belonging to X. It reflects the capacity of the model to include the true positive. In our case, results show that predicted alternatives in C2 and C3 are classified in concordance with judgment classes,while alternatives in C1 have a 39% to be correctly classified.

The user's concordance (precision) is the ratio between the number of correspondent classification in X and the total number of alternatives predicted in X (some of them couldn't really belong to X). It is the capacity of the model to avoid wrong classifications. In this case, we obtain good results in classes C1 and C2, but low results for the class C3. Looking at the data this last result is, however, acceptable. Indeed, what happens is that "conducive to walk" alternatives are frequently classified in "support walk", underestimating the real value of quality, that in our case is better than an overestimation.In other words, these results mean that this model (about class C3) can be interpreted as a "pessimistic" model, that adopts a precautionary principle. That is, in a case of uncertainty, it classifies the alternative in the lowest class.

To better understand to which extent the Electre tri model offers good rating performances (intended as classification in concordance with direct observation) an additional test consists in the comparison with a performance random classification method. A random classifier, founded on the frequency of student preferences, randomly assigns the classes with probability P(C1) = 18,3%, P(C2) = 63,4% e P(C3) = 18,3% respectively. The overall concordance of the random sorter is 33%, just more than half of the Electre tri one. This means that the Electre tri evaluates in a coincident way one alternative over three more than the random classifier, proving to be a useful predictive tool.

4.5 Prioritizing Intersections

The final aim of this study is to outline an operational method that orients policy makers in the recognition of urban needs and in the prioritization of interventions in urban-rural fringe areas for improve their livability by making them pedestrian -friendly environments and therefore support their progressive integration with the rest of the city.

With respect to this purpose the above described classification alone is not sufficient to establish an order of priority among possible interventions of improvement. In fact it is based exclusively on variables that ultimately concern spatial and operational characteristics of crossings areas and do not take account of any information about their geographical setting, such as the location of the crossing with respect to the overall urban fabric or the surrounding land uses.

We thus employ a second classification method that considers the urban quality of the context in which intersections are located and his potentialities as a walkable space. In particular we are interested in the disposition of urban setting to support the development of urban relationships, considering the improvement of walkability as an enabling spatial requirement for liveability.

The ability of the context to nurture spatial and social links with the surrounding areas, is in fact influenced by the way built environment is structured. A walkable friendly environment includes areas being traversable, physically-enticing and safe [24]. This capacity of urban space becomes fundamental for marginal areas like urban-rural fringes whose improvement of liveability strongly depend on the internal spatial quality of space as well as on the possibility to be effectively integrated in the overall urban organization.

For capturing this quality of urban space we resort to the "capability-wise walkability score" (CAWS) evaluation method [25] which is an analytical measure of mutual relations between urban organization and people’s attitudes in space. More specifically it is the result of an evaluation method founded on the capability approach paradigm which assess the quality of urban environment and its capacity to embrace and promote pedestrian mobility. It depicts to what extent built environment characteristics restrict or facilitate human experience and “use” of the city that is to say how and to what degree urban form affects participation or exclusion to urban life. In this light, it turns out to be a suitable operative tool to classify different parts of the city according to their ability or difficulty to build multiple relationships with other parts of the urban system and to stimulate human experience and action in urban space.

From an operational point of view CAWS was designed to bring together three components into a single indicator: (1) the number and variety of destinations (i.e. urban opportunities) reachable by foot from a place; (2) their distances; and (3) the quality of urban environment and pedestrian routes leading to these destinations. Thus, it takes into account both the opportunity sets distributed in urban space, as well as the characteristics of urban environment that affect walking which are relevant determinants of the relation people may entertain with that urban space. Despite the majority of walkability evaluation methods and indicators, rather than indicating how much a specific place is in itself walkable given its intrinsic place-specific characteristics, CAWS reflects where to and how a person can walk starting from that place; in other words, not how walkable the place is, but rather what is the walkability it is endowed with. According to these assumptions, CAWS assigns a walkability score to each point in space and gives maps of distribution of capability-wise walkability in space which offer a representation of how urban space is structured and experienced. Walkability maps point out differences in liveability caused by the variation of spatial qualities important for the establishment of urban relationships

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Figure 5 shows the CAW walkability map obtained for the town of Alghero with intersections and the limit of the rural urban fringe.

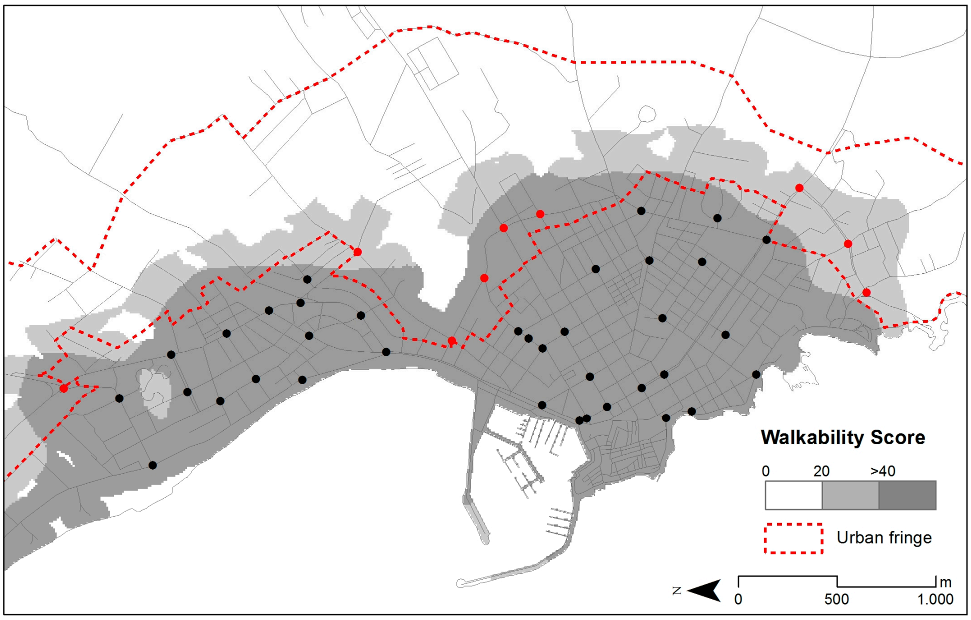

Figure 6. Comparison between intersection location and CAWS walkability score

In order to establish an order of priority among intersections, in terms of their need for improvements, we considered the following two priority criteria:

- spatial and operational performance class based on the previous rating classification (paragraph 4): each crossing is assigned to one of the three classes C1, C2, C3 ;
- walkability of the site: each crossing is assigned to one of the three classes (CAWS1, …, CAWS3) based on the "capability-wise walkability score" of the area in which it is located.

By assigning a numeric value to each crossings according to the classes and equivalent to their scale order (Borda rule) and giving weights to the two criteria we defined a priority rank which support decision making processes.

For example, according to the aim of the research, we can decide that intersection performance has the priority (weight 60%) over site walkability (40%). The resulting ranking with percentage of crossings included in the various classess are shown in Table 9.

performance class	site walkability class (order of priority)		
	CAWS1	CAWS2	CAWS3
C^1 obstacle	0,0%(4)	8,9% (2)	29,6% (1)
C^2 support	0,0% (7)	1,1% (5)	59,4% (3)
C^3 conducive	0,0%(9)	0,0% (8)	3,9% (6)

Table 9. Crossings classification according to criteria of priority (total crossings 180)

In this case crossings classified as obstacles for their spatial and operational characteristics (class C^1) and located in areas scored CAWS3 or CAWS2 deserve the highest attention (order of priority 1 and 2) because of the important role in facilitating the integration of the fringe with the rest of the city. Crossings with hindering effect (C^1) located in areas with low level of urban walkability (CAWS1) obtain a medium level of priority (4/9) while those that support walking (C^2) located in areas with high level of urban walkability obtain priority 3, thus supporting an orientation towards the strenghtening of existent favorable conditions either spatial and operational features of the intersection or structural relations of the urban setting.

With regard to intersections located within the urban-rural fringe the majority of them obtain high priority of interventions (Table 10).

performance class	site walkability class		
	CAWS1	CAWS2	CAWS3
C^1 obstacle	-	10;11;12;40	15;9
C^2 support	-	-	16;25;45
C^3 conducive	-	-	-

Table 10. Prioritization of intersection within the fringe

6. Conclusions

The paper proposes an assessment method to study and measuring the hindering effect of road intersections on pedestrian accessibility and to guide the prioritization of strategies and actions for enhancing the urban walkability in urban-rural fringe areas.

Several environmental attributes influence pedestrian decision to walk to destinations with intersections reprensenting one important hindering element. Most of the literature on walkability is generally focused on spatial features on uninterrupted sidewalks. Much less attention has been devoted to intersections, although they are constitutive components of the road network which necessarily influence people behaviors in space and the perception of safety, comfort and pleasantness of a walking route.

Through a detailded analysis and evaluation of the spatial and operational qualities of intersections and their surrounding environment we detected the disposition of the built envornment to promote walking and to improve the liveability of places.

This attitude of the urban space becomes fundamental in urban-rural fringe of the city, peripheral areas with rural and urban functions mingled together and often in conflict with each other and where the provision of spatial conditions informed to the principles of sustainability, such as the promotion of walkability and active lifestyle, represent an effective opportunity of change.

The application of the method to 45 intersections of city of Alghero led to recognize the need of including in the assessment model objective information on physical and functional attributes of crossing areas and their surroundings with pedestrian's behaviors and perceptions of the urban space.

The procedure we propose is an operational method that planners may avail of for advancing their project-oriented understanding of the city and for planning interventions aimed at improving the liveability of urban space by enhancing the safety, comfort, usefulness and attractivity of pedestrian space.

Author Contributions:

Conflicts of Interest: The authors declare no conflict of interest.

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