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UNSATISFIED-DESIRE LINES:
A Spatial Approach To Pedestrian Collision Analysis

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ABSTRACT

Safety is one of the most important conditions for pedestrian activity and a principle that should underpin any public realm scheme. However, there is still a gap in understanding where collisions and pedestrian casualties happen and thus, a lack of tools to be applied from the urban design discipline to prevent them. Our initial hypothesis is implicit in pedestrian safety guidelines: collisions take place where there is an imbalance between high pedestrian demand (pedestrian desire lines[1]) and low public realm quality. This statement has the potential to be analysed systematically and as a prevention tool.

This paper presents the case study of Peckham Town Centre, London. Peckham Town Centre was selected as part of a Transport for London (TfL) initiative to develop transport strategies with the objective of improving pedestrian safety, promote walking and to improve the overall pedestrian experience in town centres.

Pedestrian desire lines were identified using the space syntax methodology, which has proven its capacity in understanding pedestrian route choices and flows through streets network configurational analysis. In a consistent way, Visibility Graphic Analysis (VGA) of spatial configuration added to land use data offered a detailed, weighted description of pedestrian route choices. Public realm quality was assessed using PERS (Pedestrian Environment Review System). The identification of 'unsatisfied desire lines', i.e., pedestrian routes which as not supported by good, adequate design, was subsequently compared to the collision data from 2011 to 2015.

The analysis found that there was a strong correspondence between spatial morphology and the location of collisions. Surprisingly, the analysis showed little correspondence between the quality of the public realm and collision locations. Lastly, the study tested the methodology applicability to development options without compromising on urban vitality, public space connectivity or community severance.

KEYWORDS

Collision, Pedestrian safety, Space syntax methodology, Urban morphology, Visibility Graph Analysis (VGA)

1 Pedestrian desire line is defined as the preferred route a person will take to travel from A to B. Often, this is the most direct and quickest route someone can take and does not necessarily follows a 'designated path'. Parks are a clear example where visitors walk across the grass, rather than using the available paths, when those paths are not aligned with the most direct, simplest route between locations.

1. INTRODUCTION

Safety is one of the most important prerequisites for pedestrian movement in the urban environment and, thus, should be considered at the heart of any public realm scheme or masterplan. Pedestrian safety is also a matter of public health: only in Greater London, between 5,000 and 6,000 pedestrians are involved in a collision annually, of which nearly one hundred lose their lives (Transport for London, 2016). Pedestrian safety should also be safeguarded as part of all strategies seeking to encourage active, sustainable travel. Pedestrians are the most vulnerable group when looking at overall road safety: also in London, despite being involved only in 18% of all collisions, pedestrians accounted for nearly half (49%) of the fatalities (Transport for London, 2016).

It is the responsibility of planners, designers, engineers and architects to plan and design safe environments. However, there is a general lack of methodologies to assess the degree of safety that a plan or design provides, prior to its implementation and to any collision events. Another challenge is the need of applying methods to analyse urban environments at a very micro-scale, given that some studies have pointed to the important role of some micro-scale factors, such as the location of crossings, bus stops or retail units in the incidence of collisions.

Our study exams two cutting-edge methodologies – Visibility Graph Analysis (VGA), carried out using the Fathom software developed by Atkins Ltd, and Pedestrian Environment Review (PERS) – to understand the correspondence between urban environment variables and the location of collisions at the micro-scale of urban areas. These two methodologies correspond to two levels of practice: VGA analyses urban form, the impact of land use distribution and the location of transport services. These factors relate to the level of master planning and generally are not easily modifiable. In contrast, PERS addresses the perceived quality of physical elements such as the width of footways or crossings, which belong to the micro design level and are easier to modify. These two methodologies structure our study.

1.1 STATE OF THE ART: WHERE COLLISIONS HAPPEN OR WHERE PEDESTRIANS GO

Common pedestrian safety strategies to date have paid attention to both pedestrian and driver behavioural change through education, encouragement and law enforcement on the one hand, and innovations in road design, engineering and traffic calming strategies on the other hand. These strategies have been supported by studies of the influence of certain factors on collision risk, such as pedestrian characteristics, i.e., age, gender or ability or vehicle speed (Zegeer & Bushell, 2012). However, the environmental and contextual factors associated with the location of collisions involving pedestrians have been generally less studied (Moudon et al., 2008).

Pedestrian safety strategies have incorporated some urban environment issues, such as road design, lighting, maintenance, speed limits or specific equipment such as safety cameras, crash-protective objects or countdown traffic lights (Transport for London, 2013). These can be framed into the field of public realm design and, therefore, can be easily modified in a 'quick-win' street re-design project.

Yet, Moudon et al. (2008) and Shawky et al. (2014) highlight that several factors, such as the crossing typology, have limited effectiveness to promote safety. In contrast, they suggest that the highest risk of collisions take place in areas where the concentration of retail activities takes place. However, as Moudon et al. argue, retail concentration might be just a proxy measure for pedestrian activity in a given area.

This statement leads the discussion towards a different approach: should we rather focus on the factors influencing pedestrian movement? The literature has identified consistent evidence pointing at urban morphology and land use distribution as the main drivers of pedestrian activity, strongly correlated with pedestrian counts.

Based on network analysis, Space Syntax methodology (Hillier & Hanson, 1989; Hillier et al., 1993; Hillier, 2007) analyses the street network from a configurational perspective. Space syntax variables, such as choice or integration, highly correlate with pedestrian flow volumes and distribution. These variables summarise relevant topologic and geometric patterns and develop the idea of natural movement and wayfinding due to visual connections. This methodology has succeeded in identifying the pedestrian 'desire lines' of movement, mapping the places with a higher pedestrian demand and the most common pedestrian itineraries.

Within the same theoretical basis, Visibility Graph Analysis (VGA) allows the assessment of urban spaces at a more micro level (Turner et al., 2001; Desyllas & Duxbury, 2001; Turner, 2003). Space syntax representations such as axial lines (straight parts of the street network) and, later, street segments between two consecutive junctions (Hillier et al., 2010) provide a 'large' scale representation and quantification of urban spaces. In contrast, VGA enables a finer granularity and the analysis of different locations within the same street segment, with a distinction between footways, if required. This level of detail results in improved correlation coefficients with pedestrian flows (Desyllas & Duxbury, 2001).

Including land use data and transport node locations into the analysis have the potential to improve the correlation even further (Desyllas et al., 2003). This seems evident as land use density, commercial activities and public transport nodes are clear pedestrian trip generators, even though their contribution to the correlation may not be as crucial as expected (Ozbil et al., 2011). However, regardless of its overall contribution to pedestrian collision risk, consistent studies suggest the importance of land use variables, such as population and employment density (LaScala et al., 2000; Graham & Glaister, 2003), besides the concentration of retail activities introduced before.

1.2 RESEARCH QUESTIONS AND GOALS

The literature points at urban morphology, street network topology and geometry, land use distribution and density as variables that explain pedestrian volumes in the urban environment and thus the pedestrian exposure to collision risks. However, most pedestrian safety strategies deal with the urban environment at the micro level of design.

The goal of this study is hence to re-frame the subject of pedestrian collision location according to these two levels of spatial intervention: micro design versus urban form including land use. We, therefore, ask ourselves the following questions: What is the role of design quality in enhancing pedestrian safety? Are current pedestrian safety strategies right at focusing their action at the scale of the road and public realm design? Would a double approach (urban planning vs. design) support a stronger understanding of collision locational patterns? To that end, this study compares these two scales of interventions to inform, redefine or consolidate pedestrian safety strategies.

Opposing urban form and design quality leads to four space types: 'Successful pedestrian spaces' (high demand, good design quality), 'unsatisfied-desire lines' (high demand, poor design), 'back forgotten spaces' (low demand, poor design) and 'red-carpeted deserts' (low demand, good design), whereas demand relates to pedestrian flow volumes and design refers to the physical elements constituting the public realm[2] (Figure 1). All variables are analysed at the micro level of the collision location, which is also the micro level of intervention for some elements, e.g. crossings or pavements.

2 There are a range of factors that can be used to assess the design and quality of the public realm. In this study, we based our criteria on the PERS methodology (refer to Section 2.3) including suitable materials, accessibility (gradient and dropped kerbs), lack of clutter, lighting, maintenance and quality of environment. We did also consider adequate footway width in line with Transport for London guidelines (2010). This does not exclude other important design elements such as street furniture, greenery, distinctive character and desirability.

However, the urban form variables are the consequence of urban planning decisions at a more macro scale of intervention, such as the scale of a masterplan. The four fundamental typologies used to frame the topic and discussion are summarised in the Space-Type Diagram below:

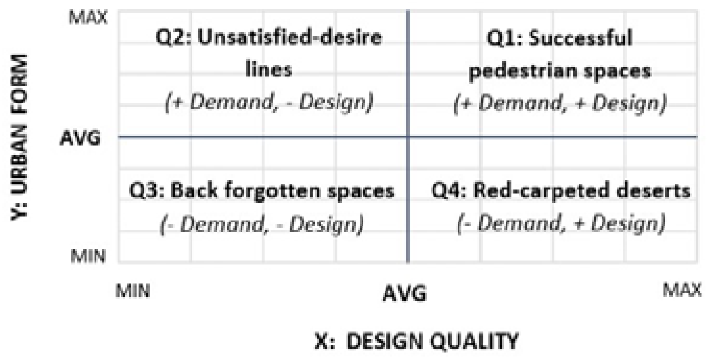

Figure 1 - Space-Type Diagram: Urban form versus Design quality

A first thought would be that pedestrian collisions are most likely to happen on 'unsatisfied-desire lines', where there is a high pedestrian demand in areas of poor design quality. Following the same reasoning, if design plays a crucial role in safety, one could assume that those places with high design standards are overall very safe, regardless of the level of pedestrian activity hosted. Likewise, one should not expect many collisions where pedestrian demand and exposure are very low.

Pedestrian safety strategies seem to accept the implicit assumption that collisions are indeed most likely to take place on 'unsatisfied-desire lines' type of locations. This study however sheds light to this assumption.

2. DATASETS AND METHODS

2.1 THE STUDY AREA: PECKHAM TOWN CENTRE

In line with Transport for London's 'Improving the Health of Londoners' Transport Action Plan, a safe and attractive urban environment can encourage people to walk and consequently to become more active. Similarly, there has been a long history of studies (Gehl, 1987; Hart, 2015; Hillier, 2007) that reiterate how accessibility is crucial for the development and sustainability of local economies and to reinforce a sense of place and the welfare of local communities. Peckham Town Centre was selected by TfL as a pilot location based on the number of pedestrians Killed or Seriously Injured (KSI) in recent years and the pedestrian safety risk[3].

The study area consists of almost 2km of the TfL's Road Network (TLRN) and 3km of local authority roads. These links exhibit a wide variety of functions: the TLRN A202 providing a major east-west arterial route from Westminster to Greenwich; Rye Lane acting as the spine of Peckham and the centre for community activity and retail; and several side streets which serve as local routes to residential areas beyond. Further, the study area comprises a typically busy urban environment with mixed use, services and residential buildings, which sees both high levels of pedestrian movement and demand for a sense of place[4] where local people can make use of local retail, social and community facilities.

The Peckham streetscape has remained largely unchanged over recent years and, apart from routine maintenance and street works, there has been no significant change to the road layout.

3 Defined as the rate of pedestrian KSIs per billion kilometres walked.
4 https://tfl.gov.uk/info-for/boroughs/street-types.

Conversely, in Peckham town centre, there are several examples of community severance, i.e. the local infrastructure acts as a physical and/or psychological barrier to the movement of people. For instance, the entrance to Peckham Rye Station is confusing, its visibility across Rye Lane is poor due to multiple obstructions, such as trader's stalls, wastes and street furniture, on narrow footways, which also limit accessibility for less mobile people. Often, people were observed walking on the road itself, increasing the risk of collisions. The access between Peckham Library, a hub of cultural activities, and Rye Lane, the shopping destination, is another example of community severance. Despite being a signalised crossing, the crossing at the junction of Rye Lane and Peckham High Street is far from safe, as highlighted by the number of casualties over the past five years.

Figure 2 - Peckham Rye Station (left) and junction of Rye Lane and Peckham High Street (right).

2.2 COLLISION DATA

Within the five-year period studied (April 2010 to May 2015)[5], the annual collision frequency in the study area was relatively unchanged, although KSI collisions[6] of all types have reduced considerably. A total of 512 collisions were recorded in the study area, resulting in 576 casualties; of these, 118 (23%) collisions involved a pedestrian resulting in 121 casualties[7], which form the main database used in this study. It is also notable that Vulnerable Road Users (VRU's), i.e., motorcyclists, pedal cyclists and pedestrians, account for 62% of all casualties in the town centre. Further, the data also showed that:

- Pedestrians, as a user group, account for the highest proportion of KSI's in the town centre, demonstrating their vulnerability when involved in a collision.
- The proportion of pedestrians involved in collisions is increasing: from 20 in 2010-11 (19% of all collisions) to 25 in 2014/15 (26%) and averaging 24 over a five-year period.

5 An excel format summary of all collision and casualty records (selected STATS19 fields only) of collisions / casualties (between April 2010 to May 2015) for the study area and KeyAccident input files detailing all collisions, casualties and vehicle records for the study area (between April 2010 to May 2015).

6 Killed: A human casualty who dies within 30 days after collision due to injuries received in the crash. Serious injury: Injury resulting in a person being detained in hospital as an in-patient, in addition to all injuries causing fractures, concussion, internal injuries, crushing, burns, severe cuts, severe general shock which require medical treatment even if this does not result in a stay in hospital as an in-patient (iRAP International Transport Statistics Database - Safety Definitions).

7 Transport for London (TfL) 'Casualties in Greater London' Fact sheets 2012, 2013, 2014.

- Pedestrian KSI's are reducing – from 2010-11 to 2014-15 there were 18 collisions with pedestrian KSI as a result (1 fatal and 17 serious casualties). Despite the increase in pedestrian injury collisions overall, the number of pedestrian injury collisions whereby a KSI injury occurred has reduced from 7 (2010-11) to 3 (2014-15) and averages 4 in number (similar to the downward KSI trend in the study area overall).

While the focus of the study was pedestrian KSI's, due to their relatively low number and reducing trend overall within the study area, all pedestrian injury collision types were therefore considered in order to establish a greater evidence base.

Even if this first study does not distinguish factors like day of the week, time of the day, gender, age, type of vehicle, it is worth noticing that the contributory factors were quite informative. Overall, pedestrian behaviour (and not the driver) was seen as the significant issue in pedestrian-vehicle collisions, suggesting that poor pedestrian behaviour, such as failed to look properly or failed to judge vehicle's path or walking speed as the main cause of collisions[8]. Most significantly, 80% of all pedestrian collisions and 60% of KSI pedestrian collisions occur at junctions, of these most are occurring at give-way / uncontrolled junctions. Further, approximately half of pedestrian collisions are classified as occurring at pedestrian crossings. All of these confirm the need of studying the on-street pedestrian perception and the spatial/design performance at the micro-scale.

A pedestrian collision 'hotspot' analysis (collision concentration[9]) have shown that out of the 18 pedestrian KSI collisions[10], the majority are concentrated on (or just off) the A202 Peckham Road/ Peckham High Street /Queen's Road corridor running east/west through the town centre comprising a total of 14 collisions (78%). Otherwise, all suggest that there are no distinct pedestrian KSI collision clusters elsewhere. Figure 3 illustrates the location of collisions according to the severity: fatal, serious or slight.

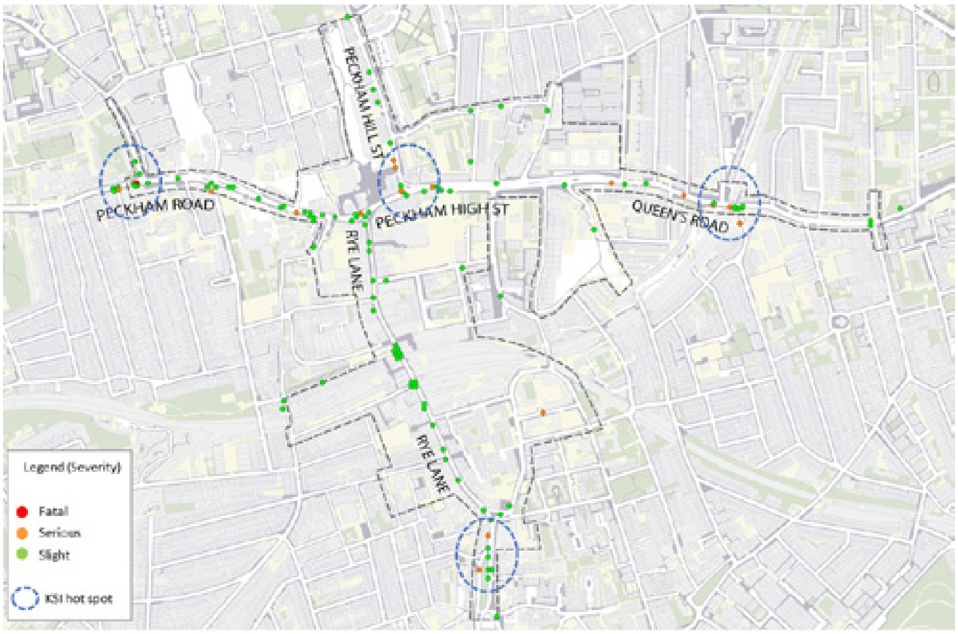

Figure 3 - Location of collisions within the study area according to the severity of collisions. Study area represented by the grey dotted line.

8 Please note that the terminology such as 'poor pedestrian behaviour' or 'failed to look properly' is set by the policy while recording the collision.

9 The concentration of KSI collisions was defined when the physical proximity was less than 50 meters.

10 Fatal or serious cases only.

2.3 TRAFFIC AND PEDESTRIAN FLOWS DATA

The levels of both vehicle and pedestrian flows at each location were also considered for the analysis.

Pedestrian flow data was collected manually by the authors and Atkins Ltd employees during lunchtime on a weekday in 2015 covering most of the street segments along Peckham Road, High Street, Queen's Road and Rye Lane providing enough information to consider pedestrian movement variability within the study area. Compatible traffic flow data was provided by the London Borough of Southwark.

2.4 DESIGN VARIABLES: PERS SURVEY

The Pedestrian Environment Review System (PERS) developed by The Transport Research Laboratory (TRL) provides a framework for assessing pedestrian provision in an urban environment. PERS has been applied to footways[11] and crossings, which were assessed on-site using an audit checklist to quantify the quality of the streetscape. The process aims to review the environment from the perspective of different users, including the elderly, disabled, children and those with impaired mobility, in order to consider the inclusivity of the public realm[12]. Following the on-site survey, using the PERS v2 software, on-site scores were collected and weighted based on TRL weighting criteria, converting the assessment into quantifiable performance values[13].

Peckham High Street and Rye Lane formed the focus of the PERS survey. Formal crossings have been examined on these roads and adjacent roads. In total 45 junctions were assessed with more than 100 crossings included as part of the review. Also, 16 segments of footways were also assessed. Overall scores have been noted alongside images documenting the full extent of the study area. Figures 4 shows the outputs of the PERS crossings and footways audit.

The results of the PERS assessment showed a number of issues, such as some uncontrolled crossings on the side road of major intersections, e.g. Clayton Road and Lyndhurst Way. On Rye Lane, there are fewer controlled crossings and pedestrians generally walk informally across the road. The study also noted that materials used along the length of Peckham High Street and Rye Lane have a low quality. Finally, it is worth to note that, for one same given location, crossings and footways do not always have the same consistent quality. Within the study area, one can find good quality crossings next to bad quality footways, and vice-versa, as well as locations with both crossings and footways with a good or bad perceived quality. In short, all combinations exist, which makes this study area perfect for this research.

11 Footways (also referred as links) were divided according to segments of consistent character and, in particular: (A) a significant change in footway width and (B) a change in adjacent land use. These two factors have been selected as they were considered to be the most influential aspects of the street environment, which impact on how pedestrians move through and across the street.

12 The assessment process for crossings looked at the following parameters: crossing provision, deviation from desire line, performance, capacity, delay, legibility, legibility for sensory impaired people, gradient, obstructions, surface quality and maintenance. The assessment process for footways looked at the following parameters: effective width, dropped kerbs, gradient, obstructions, permeability, legibility, lighting, tactile information, colour contrast, personal security, surface quality, user conflict, quality of environment and maintenance.

13 For both segments and crossings, the percentage scores attainable range from -100% to 100%, as follows: A) high quality (represented by green dots or lines): no immediate changes requires / only minor maintenance issues ranging from 34% to 100%; B) moderate quality (represented by orange dots or lines): generally operating satisfactory but could be improved ranging from -33% to 33% and C) low quality (represented by red dots or lines): critical issues identified requiring immediate attention ranging from -100% to -34%.

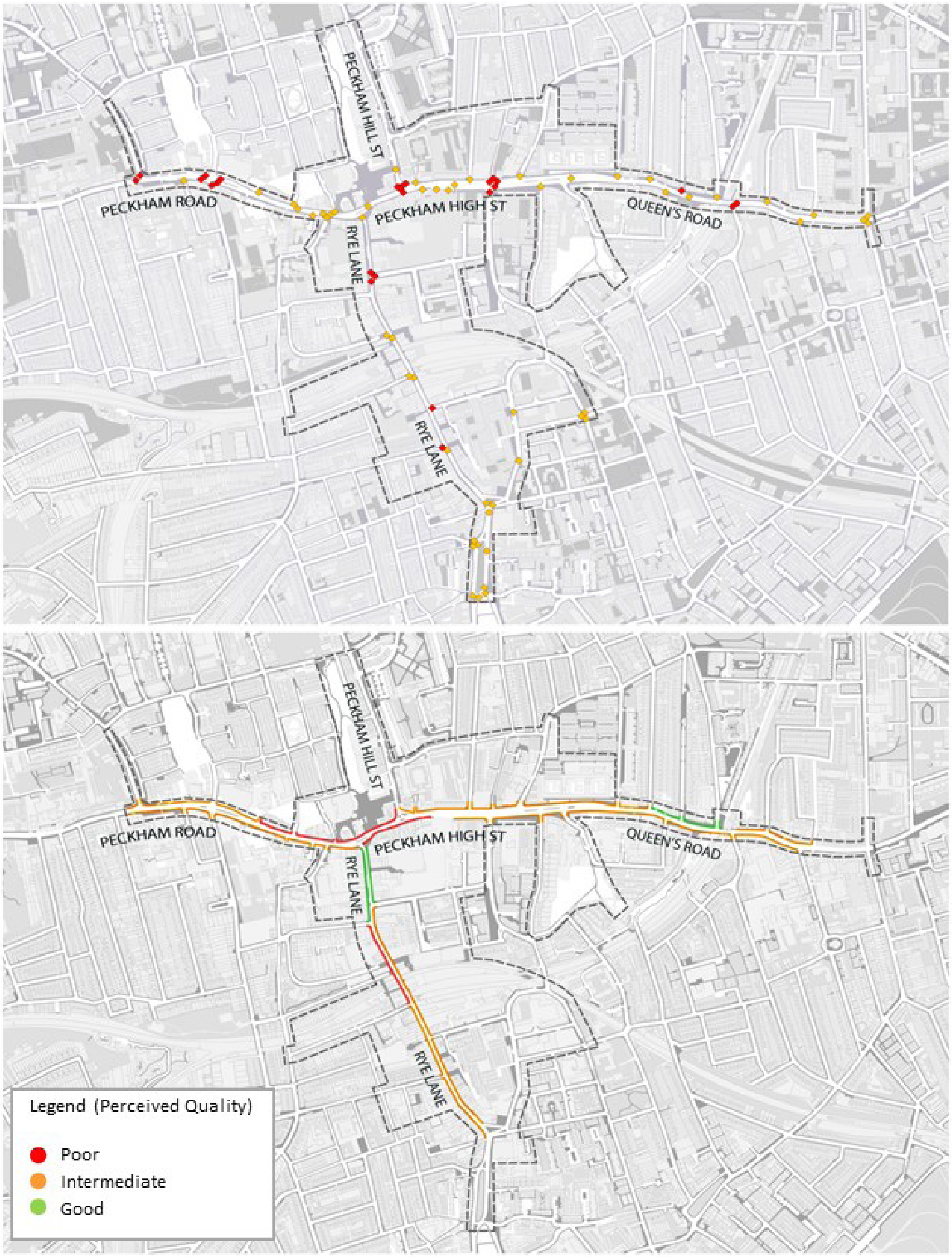

Figure 4 - PERS crossings (above) and PERS footways (below) according to perceived quality. Study area represented by the grey dotted line.

2.5 URBAN FORM VARIABLES: VISIBILITY GRAPH ANALYSIS (VGA)

Visibility Graph Analysis is based on how much space pedestrians can see as they move around. In dense urban areas, where there are many possible origins and destinations and a complexity of routes for pedestrians, pedestrians tend to choose the simplest path. This means that movement flows tend to concentrate on those streets that offer the simplest visual links through the street grid. Visibility (the area of usable space visible to a pedestrian at any point in the street grid) is, therefore, one of the most important factors determining movement. Pedestrian movement flows tend to be greater on routes that provide clear and direct visual links through the built environment than on complex routes where people cannot find a clear itinerary.

It is possible to quantify this ease of natural wayfinding within a computer model, using a methodology known as 'Visibility Graph Analysis (VGA)'. The software calculates the visual field available to pedestrians at every step of any possible journey within the network. This creates an overall measure of visibility of pedestrian space for any urban area, which can be mapped using a spectral colour range, where red indicates the highest levels of visibility through to blue, representing the lowest levels of visibility. Because of the often correspondence between visibility and pedestrian flows, VGA can be used as a representation for pedestrian flow levels.

In this study, VGA was carried out using the Fathom software developed by Atkins Ltd. Fathom calculates the visual field for a pedestrian standing at any point in the public space network. Taking accurate scale maps of an area as an input, a computer algorithm creates a 3x3 metre grid of sample observation points throughout the pedestrian movement space. The software then calculates the visual field and the number of points of interest at 360 degrees from each point in the grid by checking all directly visible points. The VGA outputs produced with Fathom are the following variables:

a) street network visibility (visible area at 50 and 500 metre distance);
b) spatial accessibility (visible area at 50 and 500 meters, directly or within one change of direction);
c) building entrances in view or natural surveillance[14];
d) retail and food/drinks units in view;
e) access to bus stops; and
f) access to railway/overground stations.

The two first variables are expressed in square metres. The two next variables in the number of units in view and are calculated twice: only directly in view or also within one change of direction. Finally, the last two variables start from 1 (direct visual connection) and sum up 1 unit per each necessary change of direction.

As discussed, the desire lines. i.e., the routes of choice by pedestrians, can be identified based on the location of the red / orange (most visible) areas in the VGA processed maps. To that end, Fathom results highlighted important desire lines of pedestrian movement such as the diagonal route linking Rye Lane and Peckham Library across Peckham High Street (Figure 5a). Further, within the context of the study area, there is a clear retail centrality formed by Rye Lane and the central stretch of Peckham High Street, in strong contrast with most back streets within the study area, which lack active frontages (Figure 5b). Finally, despite their role as key pedestrian drivers, neither of the two train stations are located at the most visible/accessible locations, an element that we have further explored in relation to the location of collisions (Figure 5c).

14 The location and visibility of building entrances not only is an important factor in the concentration of pedestrian activity, but also an important aspect of the on-street safety perception. Building entrances provide a degree of natural surveillance of public spaces from building users themselves. Although windows also provide natural surveillance, building entrances offer the potential for a neighbour to intervene if a criminal act is being undertaken. The natural surveillance of an area is measured by the number of building entrances in view from every point within pedestrian areas.

Figure 5 - Three examples of VGA outputs. From top to bottom: A) visual accessibility (500m distance), B) access to retail and food/drink units (direct) and C) access to stations. The results are presented using a spectral colour scale from red (areas with the highest accessibility levels or number of retail establishments in view) to blue (areas with the lowest accessibility levels or number of retail establishments).

2.6 LINKING AND COMPARING COLLISIONS WITH SPACE AND DESIGN DATA

Using Geographical Information Systems (MapInfo Pro 15.2 software), the collision data was plotted against all spatial information. A 25-metre buffer area around each collision location was drawn and intersected with all other data to capture their properties. In case of intersection with more than one element, the aggregation method was the average weighted by length or area.

An important weakness of the study is that PERS results were not available for all collision locations. Also, some of the collisions did not happen near any crossing, so no crossing quality value could be associated. In contrast, urban form results were available for the whole study area[15].

Scatter plots have been used to display each pair of variables for the total of collisions. This sort of diagrams enables a combined comprehension of the two factors and their interrelationship. In this case, we compare urban form and land use variables with design quality values. This allows a quick visual understanding of the role of each variable.

We have produced a scatter plot for each pair of variables (Figures 7 and 8): one from the PERS design audit (x-axis) and one from the urban form analysis (y-axis). The minimum and maximum values in the study area are located at the ends of the axes, whereas both axes intersect at the study area average values (as in Figure 1). This chart allows an easy check of the distribution of collision locations according to those two variables and the four types of spaces in the study area.

Finally, after describing the location of individual collisions, these were aggregated per street segments so that relative ratios to compare with pedestrian and traffic flows were possible. Two ratios were calculated: number of collisions per segment length (km) and per vehicle flow (daily number of vehicles) and number of collision per segment length and per pedestrian flow (pedestrians per hour, total for both pavements and both directions).

These two ratios were compared with all urban form and design variables using Pearson's correlations, in order to measure the degree of association between the collision ratios and the urban environment variables.

3. RESULTS

Firstly, the comparison of urban form and land use (pedestrian demand) versus design quality has been shown in the scatter plots. As introduced before, this enables a quick understanding of the distribution of collisions. Following the discussion on the four typologies of urban form caused pedestrian demand versus design quality, the number of collisions for each type has been calculated[16] (Figure 6). It is evident that most collision points fall within the first two typologies: successful pedestrian spaces and unsatisfied-desire lines where there is high pedestrian demand, with a clearly lower importance of the design quality.

This is also further highlighted when reviewing the scatter plots (which follow the Space-Type Diagram typologies quadrants) and the consistent collision distribution pattern that is observed: whereas one can hardly see collisions plotted below the x-axis, they are common on either side of the Y-axis (Figures 7 and 8).

15 Regarding the missing data, for the urban form – design quality comparison, 39% of collision locations had no value for crossings, whereas 28% of them had no footway value. Instead of omitting these collision events, those were kept so that the urban form information would be displayed. Regarding representation in the scatter plots, they have been plotted on top of the axis as if they had average values.

16 Note that the collision points without PERS data have been counted twice within Q1-Q2 or Q3-Q4, depending on their urban form value, which explains why the sum of all percentages in Figure 9 exceeds 100%.

This means that all the urban form/land use variables showed a strong association with collision locations, with most collisions occurring in locations with a higher pedestrian demand potential than the average in the area. On the other hand, the design quality variables were not clearly associated with the distribution of collisions. Collisions took place in all kind of locations regarding the design quality spectrum.

In short, pedestrian collisions do not take place on 'unsatisfied-desire lines' only, but also in the better designed 'successful pedestrian spaces'.

	Q1: Successful Pedestrian Spaces	Q2: Unsatisfied -desire lines	Q3: Back forgotten spaces	Q4: Red-carpeted deserts
Crossings				
VIS_50M_AVG	45.8%	48.3%	20.3%	24.6%
VIS_500M_AVG	60.2%	57.6%	11.0%	10.2%
ACC_50M_AVG	56.8%	59.3%	9.3%	13.6%
ACC_500M_AVG	65.3%	63.6%	5.1%	5.1%
BEIV_1_AVG	63.6%	62.7%	5.9%	6.8%
BEIV_2_AVG	68.6%	66.9%	1.7%	1.7%
RIV_1_AVG	47.5%	44.1%	24.6%	22.9%
RIV_2_AVG	48.3%	44.1%	24.6%	22.0%
BUSSTOP_MINSTEP_AVG	66.1%	64.4%	4.2%	4.2%
STATION_MINSTEP_AVG	63.6%	57.6%	11.0%	6.8%
Footways				
VIS_50M_AVG	49.2%	39.0%	28.8%	11.0%
VIS_500M_AVG	50.0%	56.8%	11.0%	10.2%
ACC_50M_AVG	53.4%	54.2%	13.6%	6.8%
ACC_500M_AVG	55.1%	62.7%	5.1%	5.1%
BEIV_1_AVG	53.4%	65.3%	2.5%	6.8%
BEIV_2_AVG	58.5%	67.8%	0.0%	1.7%
RIV_1_AVG	33.1%	53.4%	14.4%	27.1%
RIV_2_AVG	33.1%	54.2%	13.6%	27.1%
BUSSTOP_MINSTEP_AVG	55.9%	63.6%	4.2%	4.2%
STATION_MINSTEP_AVG	48.3%	65.3%	2.5%	11.9%

Figure 6 - Percentage of collisions according to VGA measures and space type[17].

17 Abbreviations stand for: VIS = street network visibility, ACC = spatial accessibility, BEIV = building entrances in view, RIV = access to retail and food / drinks units, BUSSTOP = access to bus stops, STATION = access to railway and/or over ground stations. 1=direct visibility, 2=direct visibility or within 1 turn, AVG = average value at location.

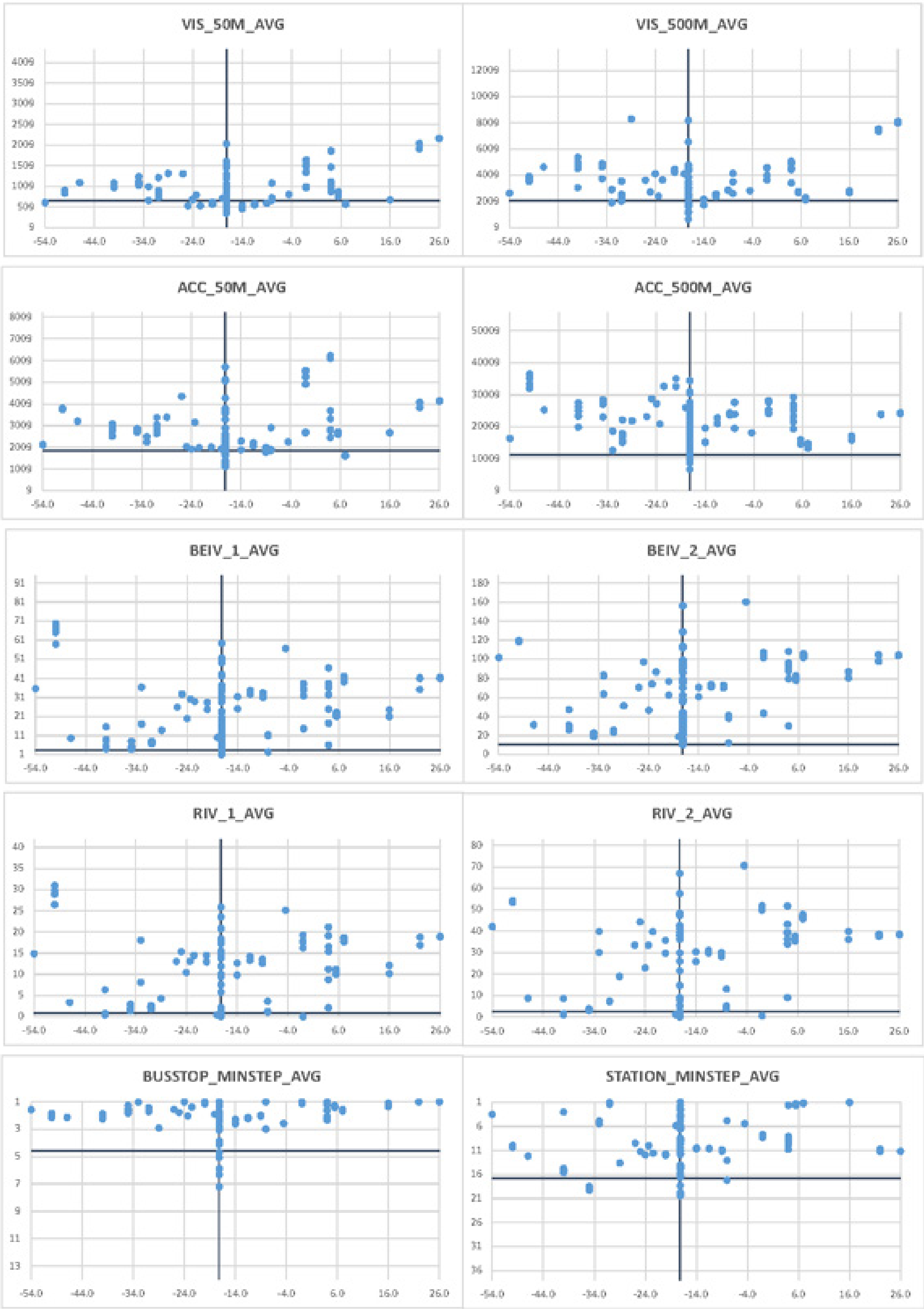

Figure 7 - Scatter plots: PERS Crossing (X) versus Urban form and land use variables (Y).

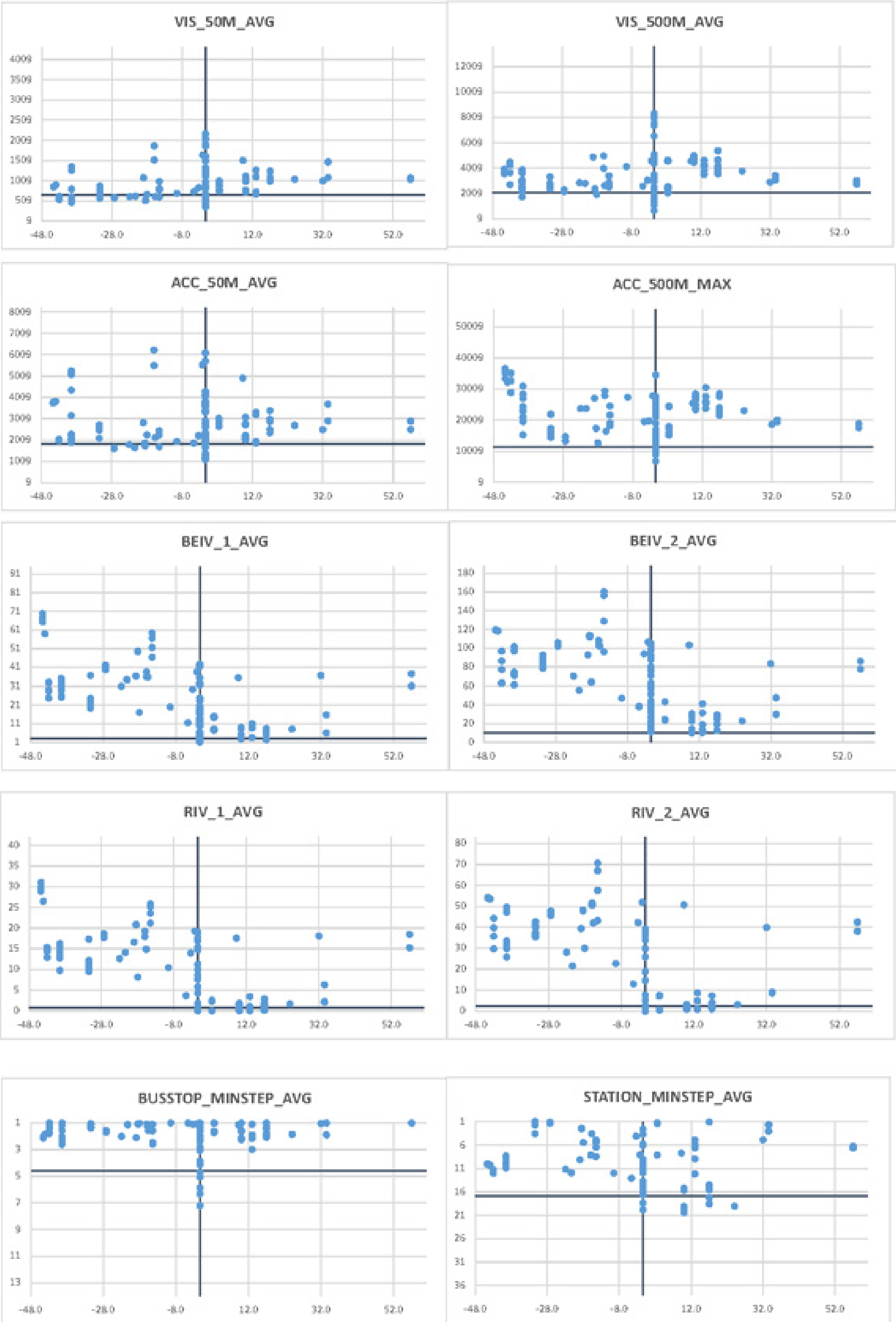

Figure 8 - Scatter plots: PERS Footways (X) versus Urban form and land use variables (Y).

To allow comparison between variables, another way to look at the results is the variation of the average value. What is the collision location average in comparison with the whole study area average? We have analysed the deviation for each variable range in the study area (Figure 10), using the formula below:

$$\text{Average value variation (as \%)} = \frac{\text{AverageCOLLISIONS} - \text{AverageSTUDY AREA}}{\text{MaxSTUDY AREA} - \text{MinSTUDY AREA}}$$

Regarding the morphological variables[18], the results show that the more strategic configurational variables are (accessibility over visibility; 500m over 50m distance), the higher the variation (+18.63% for accessibility at 500m). The location of building entrances, retail units, bus stops and transport stations are all even more significant than the morphological variables, in that order of importance (+27.19%, +24.5%, +21.54% and +19.79% respectively). This is consistent with the literature in relation to pedestrian volumes, as described in the introduction.

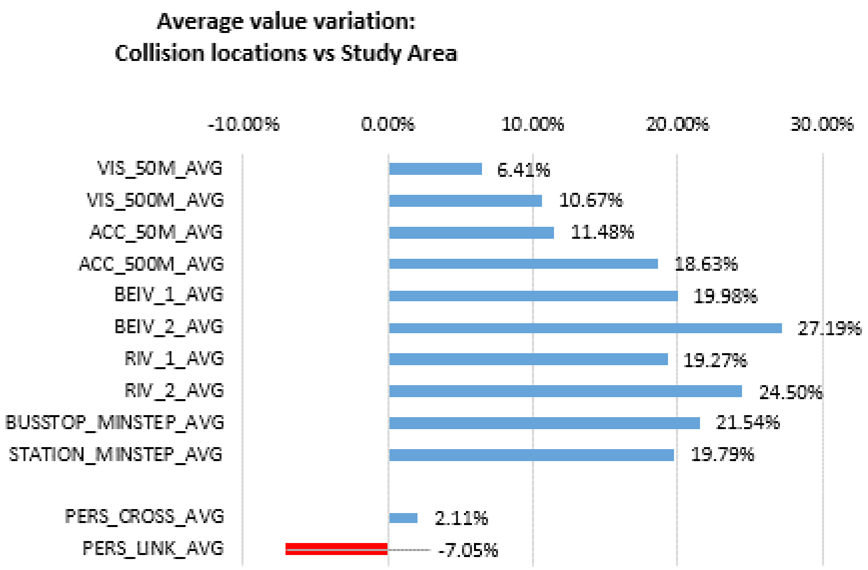

Figure 9 - Average value variation: collision locations vs study area.

The average value variation for the design variables is weaker. The quality of footways around collision locations is generally lower (-7.05%) than in the overall study area. Surprisingly, the quality of footways is slightly better (+2.11%) around the collision locations. This might be due to recent refurbishments at some of the busiest street segments, such as the northern end of Rye Lane.

18 They morphological variables are: street network visibility (visible area at 50 and 500 metre distance), spatial accessibility (visible area at 50 and 500 meters, directly or within one change of direction), building entrances in view or natural surveillance, retail and food/drinks units in view, access to bus stops and access to railway/over ground stations. Refer to Section 2.4.

Finally, regarding the two collision-flow ratios and the correlation with the urban form and design variables (Figure 10), the results showed to be not as consistent. Firstly, 14 out of the 24 correlations were not considered significant even at the 0.05 level (two-tailed). This could be expected given the low sample size (29 street segments) [19]. Further, quite relevant to note is that none of the correlations with design variables were significant (consistent with previous results), as welll as 'combined variables' such as pedestrian flows / vehicular flows ratio and pedestrian flows x vehicular flows. Looking at the significant results, we have (Figure 10):

a) For the similar levels of vehicular flows [20], the collisions per vehicle ratio shows that collisions are more likely to take place at locations with a higher number of building entrances (R=+0.39), retail units (R=+0.43) or close to a public transport station (R=-0.38). This would be consistent with our previous hypothesis and results: all these variables are a proxy for higher pedestrian flows and subsequenlty the higher the likelyhood of a collision.

b) However, assessing separatelly the correaltion between number of collisiosn and similar levels of pedestrian movement, it seems that collisions are less likely to take place at locations with higher number of building entrances (R=-0.39), retail units (R=-0.45) or close to a station (R=0.47). This might seem a contradiction with the previous results except that, in this case, the variability of these factors is not working as a proxy of pedestrian flows, given that the ratio is a relative measure per pedestrian. This would point at the interrelationship of these variables and traffic flow: in locations with aconcentration of retail units, freight traffic and / or operations often have traffic-calming and speed reduction measures and bespoke schemes to safetyguard pedestrians with a positive impact on pedestrian safety. This is the case of the north section of Rye, where only buses are allowed, so overall traffic flow is very low and the collision probability is lower despite the high retail concentration.

It is suggested that this might be related to the traffic-calming and speed reduction measures inplemented in these areas, which reduce considerably the likelyhood of collisons and the severity of injuries.

19 Further research with a larger data set (possibly including several areas in London and / or other urban areas) is needed to achieve more significant conclusions.
20 As a stand anole variable, i.e., and disregarding vehicular flows.

Correlations		Collisions per km / Traffic flow	Collisions per km / Ped flow
VIS_50M	Pearson Correlation	-.042	.024
	Sig. (2-tailed)	.828	.900
VIS_500M	Pearson Correlation	-.294	.389*
	Sig. (2-tailed)	.121	.037
ACC_50M	Pearson Correlation	.002	-.016
	Sig. (2-tailed)	.993	.932
ACC_500M	Pearson Correlation	-.402*	.165
	Sig. (2-tailed)	.031	.393
BEIV_1	Pearson Correlation	.317	-.372*
	Sig. (2-tailed)	.094	.047
BEIV_2	Pearson Correlation	.386*	-.394*
	Sig. (2-tailed)	.039	.035
RIV_1	Pearson Correlation	.365	-.430*
	Sig. (2-tailed)	.052	.020
RIV_2	Pearson Correlation	.430*	-.454*
	Sig. (2-tailed)	.020	.013
BUSSTOP_MINSTEP	Pearson Correlation	-.248	-.074
	Sig. (2-tailed)	.195	.704
STATION_MINSTEP	Pearson Correlation	-.376*	.466*
	Sig. (2-tailed)	.044	.011
PERS_Crossings	Pearson Correlation	.304	-.243
	Sig. (2-tailed)	.123	.222
PERS_Footways	Pearson Correlation	.023	.191
	Sig. (2-tailed)	.907	.320

*. Correlation is significant at the 0.05 level (2-tailed).

						POSSIBLE INTERPRETATIONS
A	**SIMILAR TRAFFIC** (as ratio per traffic)	**MORE** BEIV, RIV, etc.	=	**MORE** COLLISIONS	→	Pedestrian flow can vary with BEIV, RIV, etc.] **Same** traffic + **More** pedestrians = **More** collisions.
B	**SIMILAR PEDESTRIAN FLOW** (as ratio per pedestrian)	**MORE** BEIV, RIV, etc.	=	**LESS** COLLISIONS	→	*Pedestrian flow variation is not reflected, even if BEIV/RIV/etc. rises.* Collisions may decrease because of: - Formal or informal traffic calming due to retail concentration, freight, etc. - Traffic constraints. **Same** pedestrians + **Less/slower** traffic = **Less** collisions.

Figure 10 - Correlation results, R values and possible interpretations.

4. CONCLUSIONS

Our analysis shows that there is a strong correspondence between the location of collisions and urban form and its configurational measures, including the number of building entrances, retail and food/drinks units in view and the location or transport nodes (bus stops and rail). This finding is consistent with previous research highlighting the key drivers for pedestrian movement that correlates with pedestrian flows and exposure to traffic. In sum, collisions are more likely to happen where people go.

However, the fact that design quality variables seemed to play no significant role in the location of collisions is surprising, especially if we consider that most pedestrian safety guidelines are very design-focused.

It could be argued that the PERS method might not reflect the design characteristics affecting safety well enough. In fact, previous literature has focused on the type of crossings, traffic lights and other elements, rather than the on-street perceived quality of design.

However, this study shows that 'unsatisfied desire lines' are not the only types of spaces in which collisions take place. Locations with the highest design quality also host collision events and are not necessarily safer. Consequently, pedestrian safety strategies based on design only may not have the expected level of impact and success.

Our research suggests that an analysis of urban form and land use is key to identify the pedestrian 'desire lines' and exposure to collisions. The holistic understanding of the spatial hierarchies of pedestrian movement in a given environment can guide other initiatives, such as the strategic location of design investment, traffic-calming areas or behavioural change programmes. It would also identify the areas where the highest traffic flow itineraries are a threat and should be deviated.

Further research with a larger data set (possibly including several areas in London and / or other urban areas) is needed to strength the initial findings of this research.

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