DESIGNING FOR "LIFE BETWEEN BUILDINGS": MODELING THE RELATIONSHIP BETWEEN STREETSCAPE QUALITIES AND PEDESTRIAN ACTIVITY IN GLASGOW, SCOTLAND

A Thesis

Submitted to the Department

of

Architecture

by

John Alexander Maxwell

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

November 2016

University of Strathclyde

Glasgow, United Kingdom

DECLARATION OF AUTHENTICITY AND AUTHOR'S RIGHTS

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: J. Alexander Maxwell

Date: 20 November 2016

For Mom

ACKNOWLEDGEMENTS

I am grateful for all of the support I have received from my research supervisors, colleagues, friends, and family during the course of this four-year study. Your support has helped me develop both academically and personally in ways that I would not have been able to on my own. Professor Sergio Porta, Dr. Ombretta Romice, and Dr. David Rowe thank you for your patient guidance and constant encouragement. Professor Reid Ewing thank you for your external advice on the development of my research design and statistical analysis. Ms. Rebecca Alencar, Ms. Luisa Menezes Gusmao, Mr. Alisson Pazetto de Oliveira, Ms. Joseane Ruivo, Ms. Cintia Silva de Brito, and Ms. Monique Vale Szpoganicz thank you for your assistance with the testing and validation of my research methodology. Ms. Aileen Alexander, Mr. Andrew Agapiou, Ms. Catriona Mirren, Mr. Harry Stokes, and rest of the Department of Architecture staff thank you for all of your behind-the-scenes help. Callum, Laura, Davie, and Margherita thank you for welcoming me into your lives and making Glasgow feel like home. Mom, Ruthie, Ian, William, and John thank you for your lifetime of love and support. And Ellie, none of this would have been possible without you – I love and thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Maxwell, John A. Ph.D., University of Strathclyde, November 2016. Designing for "Life Between Buildings": Modeling the Relationship Between Streetscape Qualities and Pedestrian Activity in Glasgow, Scotland. Thesis Supervisors: Sergio Porta , Ombretta Romice, and David Rowe.

Rising levels of physical inactivity, among other pressing urban issues, have prompted urban designers to better understand the complex relationship between the built environment and human behavior. One of the most widely-cited measures of the built environment, as it relates to human behavior, is walkability – the measure of how conducive a place is to walking and other pedestrian activity. To date, walkability has largely been characterized by macroscale measures, such as street connectivity and neighborhood density. More recently, several walking audit instruments have also been developed to measure microscale features of pedestrian environments, like the number of street trees or pieces of street furniture. Yet, both of these measures fail to capture potentially important perceptual qualities of streetscapes that urban designers have long claimed as significant factors for more active streets. However, there is a surprising lack of empirical evidence in support of these claims based on validated, objective measures of streetscape qualities.

The purpose of this study was to address this gap in research by modeling the relationship between objective measures of streetscape qualities and pedestrian activity in Glasgow, Scotland. Overall, five measures of streetscape qualities – including imageability, enclosure, human scale, transparency, and complexity – were collected from over 690 street segments across the city, along with several macroscale measures of walkability and pedestrian counts. The results of this study indicated that the five objective measures of streetscape qualities added significantly ($p \leq 0.05$) to the explanatory power of walkability models when controlling for standard macroscale measures of walkability. Measures of imageability and transparency, in particular, had significant ($p \leq 0.05$) relationships to pedestrian activity ($p = 0.02$ and $p = 4.60\text{E-}14$ respectively). These results suggest that streetscape qualities should be considered as important variables in future, city-wide studies linking measures of the built environment to pedestrian activity.

"Beyond functional purposes of permitting people to get from one place to another and to gain access to property, streets – most assuredly the best streets – can and should help to do other things: bring people together, help build community, cause people to act and interact, to achieve together what they might not alone … The best streets create and leave strong, lasting, positive impressions; they catch the eyes and the imagination. They are joyful places to be, and given a chance one wants to return to them. ***Streets are places for activity****" (A. Jacobs, 1993, p. 312).*

CHAPTER 1. INTRODUCTION

Why is it easy to spend several hours wondering the streets of Paris, New York, or Edinburgh? What qualities make certain streets seem more enjoyable, inviting, or walkable than others?

Streets are one of the most important, permanent, and defining elements of the public realm that have evolved over time to reflect changes in the way cities are designed and developed (Maxwell & Wolfe, 2014; Porta, Romice, Maxwell, Russell, & Baird, 2014). They not only provide a link between daily amenities but also a context for public life. Parks, plazas, and other city spaces also remain important contexts for activity (Whyte, 1980), or what Jan Gehl referred to as the "life between buildings" (1987). However, local pavements and streets are one of the most commonly used urban environments for pedestrian activity. This is especially true in Scotland, where a secondary analysis of Scottish Health Survey data revealed that over 50% of respondents reported using local pavements[1] or streets at least once a

[1] *Pavements* are also referred to as *sidewalks* in American English.

week – more than any other physical activity[2] environment, including gardens, parks, and sports centers (Mitchell, 2013, p. 132).

Understanding the nature of the relationship between measures of the built environment and pedestrian activity has remained one of the fundamental challenges within the field of urban design. As Ewing et al. noted, "the role of the built environment in influencing travel behavior may be the most widely researched topic in urban planning" (Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2015, p. 5). One of the most important and widely-cited measures of the built environment, as it relates to travel behavior, is walkability – the measure of how conducive a place is to walking and other pedestrian activity. Until recently, macroscale measures of the built environment related to walkability, including density, diversity, destination accessibility, distance to transit, and street network design, have formed the basis for much of the evidence describing the relationship between the built environment and pedestrian activity (Ewing & Cervero, 2001, 2010). However, macroscale measures alone do not reflect pedestrians'

[2] The terms *pedestrian activity* and *physical activity* are often used interchangeably in the walkability literature. Physical activity is broadly defined by the World Health Organization (WHO) as "any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2014). However, the term *pedestrian activity* refers to a subcategory of physical activity defined in this study by walking, running, sitting, or standing behaviors along a street.

experience with the built environment. As Harvey and Aultman-Hall stated, "empirical built environment research has tended to focus on the *macroscale* layout and development of whole neighborhoods or cities. These describe how streetscapes relate to one another from an overhead perspective but do not capture the sizes and shapes of individual streetscape spaces" (2016, p. 149). In short, macroscale measures of the built environment do not capture potentially important microscale factors of pedestrian streetscapes[3] that may also influence pedestrian activity (Cain et al., 2014; Millstein et al., 2013).

As a result, over the past decade and a half, several tools known as walking audit instruments, have also been developed to measure microscale features of pedestrian streetscapes (e.g., Boarnet, Day, Alfonzo, Forsyth, & Oakes, 2006; Clifton, Livi Smith, & Rodriguez, 2007; Day, Boarnet, Alfonzo, & Forsyth, 2006; Hoehner, Ivy, Brennan Ramirez, Handy, & Brownson, 2007; Millington et al., 2009; T. J. Pikora et al., 2002; Shriver, 2003). These instruments typically measure individual streetscape features such as the number and height of buildings or pieces of street furniture. However, as has been argued by Ewing and Handy, "physical features individually may not tell us much about the experience of walking down a street. Specifically, they

---

[3] The term *streetscape* refers to "urban roadway design and conditions as they impact street users and nearby residents" (Victoria Transport Policy Institute, 2016).

do not capture people's overall perceptions of the street environment, perceptions that may have complex or subtle relationships to physical features" (2009, p. 66).

The importance of these perceptual streetscape qualities and their relationship to pedestrian activity has been written about extensively in the urban design literature (e.g., Cullen, 1961; Gehl, 1987; A. Jacobs, 1993; A. Jacobs & Appleyard, 1987; J. Jacobs, 1961; Lynch, 1960; Rapoport, 1990; Sitte, 1889; Whyte, 1980). A literature review of classic works in urban design and visual preference and assessment literature generated a list of over 50 perceptual, streetscape qualities ranging from complexity to transparency (Ewing & Handy, 2009)[4]. Yet, as the authors of this review noted, "[w]ith few exceptions, the urban design literature has not attempted to objectively measure these or other perceptual qualities, and instead simply asserts their importance" (Ewing & Handy, 2009, p. 66).

While recently some progress has been made in operationalizing objective measures of streetscape qualities (Clemente, Ewing, Handy, & Brownson, 2005; Ewing, Clemente, Handy, Brownson, & Winston, 2005; Ewing &

---

[4] See Table 1 from Ewing and Handy (2009, p. 66) for full list of perceptual streetscape qualities.

Handy, 2009; Ewing, Handy, Brownson, Clemente, & Winston, 2006), only a handful of limited field studies have attempted validate these measures in large-scale walkability studies (Ameli, Hamidi, Garfinkel-Castro, & Ewing, 2015; Ewing & Clemente, 2013c; Neckerman, Purciel-Hill, Quinn, & Rundle, 2013). The primary purpose of this study was to improve upon the limitations of past field studies by modeling the relationship between objective measures of streetscape qualities and pedestrian activity in over 690 street segments throughout Glasgow, Scotland, while controlling for macroscale measures of walkability. By doing so, this study not only represents the largest and most rigorous of its kind ever conducted but also adds to the current understanding of how streetscape qualities relate to pedestrian activity and might be used to improve the design of streets as "places for activity" (A. Jacobs, 1993, p. 312).

1.1 Background of the Problem

Over the past several years, the fields of urban design and public health have united under a common interest in walkability. According to Lee and Talen, "[w]alkability is now regarded as a key factor in the promotion of health and environmental goals" (2014, p. 368). Walkability, as it relates to health, is now often linked with goals of promoting more active urban environments, while also being associated with efforts to curb vehicle miles traveled and reduce sprawl and emissions (Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006; Ewing et al., 2008; L. D. Frank et al., 2006).

1.1.1 Issue of Physical Inactivity

According to the World Health Organization (WHO), physical inactivity is the fourth leading risk factor for global mortality, causing 6% of all deaths (or approximately 3.2 million deaths) every year, and is on the rise in many countries, increasing the burden of non-communicable diseases (WHO, 2010, 2014). In the UK, physical inactivity causes: 10.5% of the burden of disease from coronary heart disease, 18.7% of colon cancer, 17.9% of breast cancer, 13.0% of type 2 diabetes, and 16.9% of premature all-cause mortality (I.-M. Lee et al., 2012). A quarter of British adults now walk for less than nine minutes a day, including time spent getting to the car, work, and the shops (Design Council, 2014). Additionally, the annual ill health cost of physical inactivity to the National Health Service in the UK was estimated at £0.9 billion (Scarborough et al., 2011), with more recent data showing that these costs have been increasing (British Heart Foundation National Centre, 2013).

Decreasing levels of physical activity often correspond with higher or increasing gross national product, partly due to inaction during leisure time and sedentary behavior. However, increases in the use of passive modes of transportation (e.g., motorized transport) similarly contribute to inactivity, along with other factors linked to urbanization, including: crime, traffic, air pollution, and lack of parks, pavements, and recreation facilities (WHO, 2014). While there are many potential correlates of pedestrian activity, including demographic, biological, social and cultural variables (Bauman et al., 2012), those related to measures of the built environment are believed to be among some of the most important.

1.1.2 Challenge of Designing "Places Where People Want to Be"

In Scotland, it has been recognized that "[t]he need to cater for motor vehicles is well understood by designers, but the passage of people on foot and cycle has often been neglected" (Scottish Government, 2010, p. 8). As noted by the Scottish Council of Economic Advisors:

> *"Too much development in Scotland is a missed opportunity and of mediocre or indifferent quality. There are a few examples of new or regenerated places which are well thought out…The ultimate test of an effective planning system is the maintenance and creation of places where people want to be" (Scottish Council of Economic Advisers, 2008, p. 44).*

The need to plan for and design places – especially streets – where people want to be is not limited to Scotland and has been stressed as a key priority to urban development in several recent publications (e.g., Chartered Institution of Highways and Transportation, 2010; Department for Transport, 2007; Scottish Government, 2010; United Nations Human Settlements Programme, 2013). However, understanding the relationship between measures of the built environment and pedestrian activity has remained one of the fundamental challenges within the field of urban design.

1.2 Statement of the Problem

Until recently, the walkability of built environments has often been characterized according to macroscale measures of density, diversity, destination accessibility, distance to transit, demographics, and street network design – collectively referred to as the "D variables" (Cervero & Kockelman, 1997; Ewing & Cervero, 2001). Taken on their own or in combination, these variables can often be easily and objectively measured using reliable secondary data sources and geographic information systems (GIS) analysis tools (Ross C. Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). However, as Millstein et al. have claimed, "[m]acro-level factors do not reflect the entirety of people's experiences with their environment" (2013, p. 1). That is, they cannot capture pedestrian perspectives of urban streetscapes, and as Cain et al. have argued, “studying microscale features may also be useful for understanding physical activity” (2014, p. 83).

On a pedestrian scale, more complex and labor-intensive tools have emerged for measuring streetscape features, often referred to as walking audit instruments. These tools typically require in-person audits, measuring individual streetscape features, such as building heights, setbacks, and block lengths. More recently, researchers have also started exploring ways to virtually audit pedestrian street environments using tools such as Google Street View (Google Inc., 2016) and GIS (Esri Inc., 2015) (e.g., Badland, Opit, Witten, Kearns, & Mavoa, 2010; Clarke, Ailshire, Melendez, Bader, & Morenoff, 2010; Odgers, Caspi, Bates, Sampson, & Moffitt, 2012; Rundle, Bader, Richards, Neckerman, & Teitler, 2011; Wilson et al., 2012) as a way to reduce the costs and time associated with in-person walking audits. However, individual features may not fully capture pedestrians’ overall perceptions of streetscape qualities – qualities that are presumed to have an important relationship with pedestrian activity, despite a lack of empirical evidence based on validated, objective measures of streetscape qualities (Ewing et al., 2006).

1.3 Studies Addressing the Problem

Recently, several studies have attempted to address this gap in the understanding of how streetscape qualities relate to pedestrian activity. The first of these studies started by establishing operational definitions and measurement protocols for streetscape qualities related to walkability (Clemente et al., 2005; Ewing et al., 2005; Ewing & Handy, 2009; Ewing et al., 2006). In these studies, over 50 perceptual, streetscape qualities[5] and 130 related streetscape features were identified based on past reviews of both classic works in urban design and visual preference and assessment literature. Later, only five of these qualities – imageability, enclosure, human scale, transparency, and complexity – were successfully operationalized as objective measures related to walkability by a panel of experts from the fields of urban design and public health. Each streetscape quality was linked to a set of individual streetscape features using best-fit models and operationalized according to the following criteria: (1) if the quality had no correlation to overall walkability (i.e., the null hypothesis was true), the probability of a type 1 error (α) was less than or equal to 5 in 100 (i.e., $p \leq 0.05$); (2) the degree of agreement among independent, expert panel raters

[5] Perceptual, streetscape qualities were referred to as "urban design qualities" in previous studies but the terms are intended to be synonymous.

(i.e., inter-rater reliability) in measuring the quality was at least "moderate" according to the relative strengths of agreement suggested by Landis and Koch (1977)[6] (intra-class correlation coefficients, ICC ≥ 0.4); (3) measurable streetscape features accounted for 30 percent or more of the total variance in ratings of the quality; (4) measurable streetscape features explained 60 percent or more of the sample-specific variance in ratings of the quality; and (5) all streetscape features related to ratings of the quality were measured with at least a "moderate" degree of inter-rater reliability (ICC ≥ 0.4). While each of the five streetscape qualities met the strict operationalization criteria listed above, only limited field studies were conducted at the time to test for further validation of the measures.

Subsequently, only two preliminary field studies have ever been conducted based on the objective definitions of streetscape qualities and measurement protocols operationalized in these previous studies. The first of these studies was conducted in New York City (Ewing & Clemente, 2013c; Neckerman et al., 2013). This study used pedestrian counts from four separate walk-throughs to generate average pedestrian counts on 588 randomly selected

[6] While Landis and Koch (1977) benchmarks were used, it would be more appropriate to use cutoffs suggested by Cicchetti (1994), which still indicate "fair" agreement at ICC values > 0.4.

street segments. These counts were collected in person and used as measures of pedestrian activity, the dependent variable in the study. Measures of imageability, enclosure, human scale, transparency, and complexity were also collected, and macroscale measures of several D variables were generated at each sample street segment and used as the independent and control variables respectively. These variables were then used to model the relationship between streetscape qualities and pedestrian activity. Results indicated that the measures of streetscape qualities, when taken collectively, significantly ($p \leq 0.05$) improved the explanatory power of the overall walkability models. Additionally, one of the five streetscape qualities – transparency – was found to be directly and significantly related ($p \leq 0.05$) to pedestrian activity. This preliminary finding provided initial field validation of the previously-developed protocol for measuring streetscape qualities.

Following this study, Ameli et al. (2015) conducted a similar, but albeit smaller-scale, study in the downtown "Free Fare Zone" area of Salt Lake City (SLC). Using a similar protocol on 179 street segments, Ameli et al. also found that their walkability models were significantly ($p \leq 0.05$) improved with the addition of streetscape qualities, when controlling for macroscale D variables. Transparency was similarly shown to be directly and significantly ($p \leq 0.05$) related to pedestrian activity. However, the results of this study also indicated that a second streetscape quality – imageability – had a significant relationship ($p \leq 0.05$) to pedestrian activity, showing for the first time that perhaps more than one individual streetscape quality could be directly and significantly related to pedestrian activity.

1.4 Deficiencies in Past Studies

The studies mentioned above represent important gains in improving the methods for objectively measuring streetscape qualities and also provide valuable preliminary evidence in support of past claims regarding the relationship between streetscape qualities and pedestrian activity. However, these studies were not without limitations.

Firstly, New York City is one of America's most unique, walkable[7], and compact[8] cities. As such, this limited the generalizability of the results. As Ewing and Clemente suggested, "[o]ur first recommendation would be to repeat this validation study in more typical cities" (Ewing & Clemente,

---

[7] The New York City metropolitan area has the highest walk mode share of any large metropolitan area, 21.4 %, according to the US Department of Transportation Federal Highway Administration's National Household Travel Survey (U.S. Department of Transportation Federal Highway Administration, n.d.). Four of the five counties in New York City metropolitan area (New York County, Kings County, Bronx County, and Queens County) rank as the four most compact counties in the USA according to their sprawl index values (Ewing, Schieber, & Zegeer, 2003).

[8] Four of the five counties in New York City metropolitan area (New York County, Kings County, Bronx County, and Queens County) rank as the four most compact counties in the USA according to their sprawl index values (Ewing et al., 2003).

2013c, p. 98). The study by Ameli et al. attempted to overcome this limitation by centering their study in SLC, a city "more typical of the auto-dependent United States as compared to NYC" (p. 395). However, while the study by Ameli et al. may have represented a more "typical" case, the study was also limited by its relatively small sample size (n = 179 street segments) and narrowly-focused study area. Ameli et al. noted:

> *"This study is not without limitations. The sample size, 179 block face segments, is small, relatively speaking. Additionally, the homogeneous environmental pattern of the study area reduces data variation and contrast. For example, block length and intersection density are exceptionally unified within downtown SLC" (2015, p. 406).*

Ameli et al. suggested that "further validation of walkability should include larger sample sizes in study areas with varying environmental patterns" (Ameli et al., p. 406).

Secondly, the reliability of the average pedestrian counts in the New York City study was limited by the relatively small number of counts and lack of standardization. Ewing and Clemente explained:

"The main threat to the reliability of our results is the limited counts done on each block face. The day and time of the counts were variable. Only four counts were done on each [street segment], as field observers walked up and down the block. Our second research recommendation would be to conduct longer standardized counts on each street segment in any future study" (2013b, p. 98).

Ameli et al. overcame this limitation by standardizing longer pedestrian counts to get a more representative sampling of typical, weekday activity on the street. To standardize pedestrian counts, the number of people encountered at each sample street segment was counted over a 30-minute period during the months of September and October. Counts were made by a team of graduate research students during peak weekday hours of pedestrian activity (between 11:30–13:30 hours and 16:30–18:30 hours) and only on days without inclement weather (e.g., high winds or rain). While this standardization may have worked well for this particular study with a total sample size of n = 179 street segments, its application in larger, city-wide studies or those without the support of a multi-person research team is simply not feasible.

Lastly, while both of these studies used in-person audits of streetscape qualities, the value of the protocols developed by Ewing et al. (2005) are likely to be extended by implementation of improved virtual tools for data collection and analysis. Some work has already been done to improve methods for assessing features of the Ewing et al. (2005) protocol using virtual auditing techniques (Bader et al., 2015). However, these methods rely strictly on the use of Google Street View, which is limited by the ability to capture all relevant streetscape features, temporal variability in the images, and data availability across the entire study area. Thus, there is still scope to extend the implementation of the Ewing et al. (2005) protocols by exploring new methods for virtual data collection and analysis.

1.5 Scope of this Study

The primary purpose of this study was to improve the understanding of how streetscape qualities relate to pedestrian activity by modeling this relationship using data collected from street segments throughout Glasgow, Scotland. This study addresses previous concerns surrounding the generalizability of results and limited sample sizes by conducting the study in a typical, post-industrial European city and including a dataset of 693 sample street segments. Unlike New York City and downtown Salt Lake City study areas used in previous studies, Glasgow represents a wide variety of urban forms and design qualities, linked to its historical development over several centuries (Frey, 2004). Samples were selected from across the entire city, covering each of the small-area statistical geographies, known as datazones, within the city. This study represents the largest of its kind ever conducted and the first of its kind outside of the United States.

Additionally, this study improved upon previous methodological limitations regarding standardization of pedestrian counts by building upon the data collection method suggested by Ameli et al. (2015). While 30-minute counts at each sample location were not feasible given the geographic scale of the study area (Glasgow covers an area of approximately 175 square kilometers) and single observer, four pedestrian counts were conducted by the author in the summer months (May - August) at each sample street segment during the daylight hours (9:30AM until 4:00PM) of non-inclement weather weekdays. Counts were further validated and tested for internal consistency against counts made using separate street-level imagery supplied by Google Street View (Google Inc., 2016) and Bing Streetside (Microsoft, 2016).

Lastly, this study also represented the first time, to the knowledge of the author, that active lifestyle cameras (e.g., GoPro cameras) have been validated and used as an alternative to typical in-person audits for measuring streetscape qualities as part of a city-wide walkability study. Thus, this study extended the implementation of the Ewing et al. (2005) protocols by exploring new methods for virtual data collection and analysis in walkability studies.

1.6 Summary of Chapters

This thesis is divided into several large chapters. Chapter 2 – *Theoretical Perspective and Literature Review* presents the theoretical perspective adopted for this study – probabilism – in light of other key theoretical perspectives, including determinism and possibilism, used throughout history to describe the nature of the relationship between the built environment and human behavior. A brief review of the walkability literature is then provided in order to highlight the important gap in research (mentioned above in Section 1.4) regarding the study of perceptual, streetscape qualities and establish the hypotheses and expected findings of this study.

Chapter 3 – *Data and Methodology* details the data and methodology used in this study to address the gap in research and test the hypotheses established in Chapter 2. This chapter includes a description of the case study location, units of observation, primary and secondary data sources, as well as the methodology (with reference to the *Video Recording Protocol* and *Field Manual*

– see Appendix C and Appendix D) used for collecting the data required for this study. The final section of this chapter also briefly details additional ethical considerations made during this study.

Chapter 4 – *Results and Discussion* presents the results of this study, along with a discussion of the findings and relevant implications to policymakers, urban designers, and researchers. This chapter includes a detailed description of the statistical distribution of the dependent variable (average pedestrian counts) and how this distribution was used to select and generate the generalized linear regression model for statistically relating the control variables (D variables) and independent variables (streetscape qualities) to the average pedestrian counts. Procedures for statistical validation of the models and relevant limitations of the results are also discussed.

Lastly, Chapter 5 – *Conclusions* presents a summary of the conclusions of this thesis. This chapter includes a summary of key findings, as well as notes on the overall limitations of this study and the potential of future studies.

CHAPTER 2. THEORETICAL PERSPECTIVE AND LITERATURE REVIEW

2.1 Introduction

It is hard to deny that the way in which people live their lives is linked in some way to the design of the built environments in which they live. As Winston Churchill once said in an address to the Architectural Association in 1924:

> *"There is no doubt whatever [sic] about the influence of architecture and structure upon human character and action. We make our buildings and afterwards they make us. They regulate the course of our lives" (Brand, 1994, p. 3).*

Yet, there is a long-running debate within the field of urban design about the nature of the relationship between the built environment and human behavior.

One of the primary goals of this chapter was to establish the substantive, positivist framework used to examine the relationship between perceptual, streetscape qualities and pedestrian activity in this study. This chapter starts by briefly highlighting the primary theoretical positions, including determinism, possibilism, and probabilism, commonly used to describe the nature of the relationship between the built environment and human behavior. The theoretical perspective adopted in this study – probabilism – is then further explained as relates to this study in order to provide a foundation for the review of relevant literature.

The second section in this chapter provides a brief review of the walkability literature, focusing on the progression of studies – from macroscale to microscale – relating measures of the built environment to measures of travel behavior and pedestrian activity. This section highlights the important gap in the literature regarding the measurement of perceptual streetscape qualities and their relationship to measures of pedestrian activity. The chapter ends by proposing primary hypotheses and expected findings of this study.

2.2 Theoretical Positions Regarding the Relationship Between the Built Environment and Human Behavior

In *Creating Architectural Theory: The Role of the Behavioral Sciences in Environmental Design*, Jon Lang identified four basic theoretical positions regarding the relationship between the built environment and human behavior, which are summarized in Table 1 (1987, p. 100). Originally drawn from the work of J. Douglas Porteous (1977, pp. 135-138), these positions provided a useful set of concepts to describe the environment-behavior relationship and ultimately made it possible to establish the theoretical perspective used in this study.

Table 1 – Key theoretical positions regarding the relationship between the built environment and human behavior

Free-will approach	Deterministic approach
The built environment has no impact on human behavior	The built environment determines human behavior
Possibilistic approach	**Probabilistic approach**
The built environment is strictly the "afforder" of human behavior (i.e., the environment contains a set of opportunities for behavior, which may or may not be acted upon)	The built environment at least partially determines human behavior; e.g., "Given an individual *A* with attributes *a*, *b*, *c* set in an environment *E* with characteristics *d*, *e*, *f*, and with the motivation for action *M*, it is probably that *A* will perform behavior *B*" (Porteous, 1977, p. 138)

The overall goal in reviewing these models was not to justify a normative position on the relationship between the built environment and human behavior or to rationalize the author's particular preference. While it was necessary to eventually take a stance in support of one theoretical position – probabilism – it was recognized from the onset of this study that the nature of this relationship remains a subject of debate, and the results and conclusions from this study should be left open for further refinement. The following subsections detail the key theoretical positions, along with a description of how probabilism was used in this study to develop the theoretical framework for modeling the relationship between streetscape qualities and pedestrian activity.

2.2.1 Determinism

One of the fundamental theories linking the built environment and human behavior is the concept of determinism. Determinism, as it pertains to the built environment and human behavior, is the belief that the built environment, comprised of both artificial and natural elements, leads to changes in human behavior. This approach implies a simple cause-and-effect relationship between the built environment and human behavior, in which "the [built] environment is the independent, and human behavior the dependent variable" (Broady, 1972, p. 174).

Belief in this one-way process has been recognized as an important premise of architectural modernism and other design initiatives throughout history aimed at promoting social progress or directing human behavior (Lipman, 1974). Early expressions of the concept were manifest in the large-scale public works of Georges Eugène Haussmann and the utopian designs of Ebenezer Howard's Garden City (see Figure 1)[9]. As noted by Lang, "[t]he

[9] Belief in architectural determinism was further reinforced during the earlier twentieth century by bold social housing plans, like the Bruce Plan for the City of Glasgow (Bruce,

whole social and philanthropic movement of the latter part of the nineteenth century, which culminated in the garden cities movement led by Ebenezer Howard (1902) and the settlement-house schemes, was imbued with the spirit of architectural deterministic beliefs" (1987, p. 101).

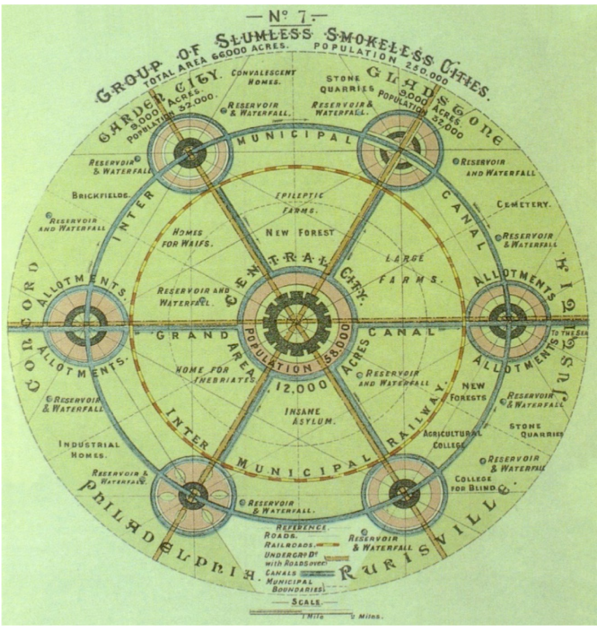


Figure 1 – The Garden City concept from Ebenezer Howard's Garden cities of tomorrow (Howard, 1902)

Despite its popularity, critics have argued that the simple, one-directional approach of determinism fails to recognize the importance of additional social factors in understanding the complex relationship between the design of the built environment and human behavior. Maurice Broady, an early

---

1945), and other notable concepts including Le Corbusier's *Ville Contemporaine* (Contemporary City) (Le Corbusier, 1929) and *Ville Radieuse* (Radiant City) (Le Corbusier, 1933), and Clearance Perry's Neighborhood Unit theory (Perry, 1929).

critic, emphasized two important limitations: (1) "[d]esigners often fail to recognize how much difference it makes to their view of the world that they respond to buildings and townscapes with eyes more discriminating and intellects more sensitive to design than those of the average layman" (1972, p. 181); and (2) "human beings are a good deal more autonomous and adaptable than a deterministic theory would lead one to suppose" (1972, p. 182). Ittelson et al. added that the unidirectional causality of strict deterministic theory ignored the "feedback role of the participant" (1974, p. 346) – i.e., the degree to which human perceptions of and react to a situation may modify the environmental stimuli to which he or she is responding.

2.2.2 Possibilism

One alternative to architectural determinism – possibilism – is a theory that treats the built environment as simply "the medium by which man is presented with opportunities," (Porteous, 1977, p. 137). In this view, the environment provides what James Gibson called "affordances"[10] (Gibson, 1966) for human behavior that limit effective behavior choices and little more. According to this theoretical approach, urban designers are thus

[10] "Affordances," as Lang described, "are those of its properties that enable it to be used in a particular way by a species. The properties of concern to Gibson are the physical properties of the configuration of an object or setting that allow it to be used for some overt activity" (1987, p. 81).

responsible for creating what Herbert Gans called "potential environments,"[11] and what is perceived subjectively and later affects human behavior becomes the "effective environment" (Gans, 1968).

However, the affordances of potential environments are not perceived and used by people in the same way. As a product of the built environment and the behaviors of people who use them, the effective environment varies for different people according to their "social background" and "way of life" (Broady, 1972, p. 181).

A purely possibilistic position suggests that individual differences in behavior occur randomly, and that people are completely free to behave as they choose. This stance thus limits the role of design to enabling some human behaviors, while excluding others. However, critics of possibilism have challenged that people are not always free to act on their own choices. As suggested by Lang, behavior does not occur haphazardly – "[i]t has a certain predictability" (1987, p. 106).

---

[11] As Maurice Broady explained, "[t]he physical form is only a potential environment since it simply provides possibilities or clues for social behavior. The effective – or total – environment is the product of those physical patterns plus the behavior of the people who use them" (Broady, 1972, p. 181).

2.2.3 Probabilism

As an alternative to determinism and possibilism, probabilism asserts that an individual's decision regarding behavior cannot be predicted, but that the "range of his [or her] possible decisions and the probability of his [or her] making any one of them can be ascertained" (Porteous, 1977, p. 138). The probabilistic position is one that recognizes the uncertainty of the complex relationship between the built environment and human behavior, but asserts that human behavior is not entirely random and can be better understood through careful study of environment-behavior patterns. As Porteous explained:

> *"Probabilism, a more moderate viewpoint which invokes common sense, asserts that lawful relationships exist between environment and behavior. Terrain, climate, and physiology do not dictate. Everywhere there exists a large number of latent opportunities and alternative possibilities for action or inaction. By the detailed study of a host of individual examples some enduring relationships between behavior, organism, and environment may emerge (Prince, 1971)" (Porteous, 1977, p. 138).*

Probabilism has become an increasingly popular alternative to determinism and possibilism as a theoretical framework for studying the relationship between the built environment and human behavior. As noted by Lang, "[t]he probabilistic position underlies most of the recent research on the relationship between behavior and environmental design" (1987, p. 100) and was the theoretical position adopted in this study.

2.2.4 Summary of the Theoretical Perspective Adopted for This Study

It has been argued that all design is intended to be persuasive or influence human behavior (Buchanan, 1985; Redström, 2006), and that the very concept that design matters is "a fundamental tenant for most design activity" (Marmot, 2002, p. 252). However, as noted in Chapter 1 and in Section 2.3 below, empirical tests of the links between measurable streetscape design qualities and pedestrian activity remain limited.

This study sought to model the relationship between streetscape qualities related to walkability and pedestrian activity in Glasgow, Scotland. In doing so, the theoretical perspective adopted in this study was decidedly positivist and probabilistic in its outlook, implementing a theoretical-deductive mode of inquiry[12]. As emphasized by Lang, the whole role of positive theory in the

[12] A theoretical-deductive mode of inquiry is one in which, as Anne Vernez Moudon explained, "a theory is developed on the basis of past knowledge, which is then tested via research" (1992, p. 336).

field of urban design is to "enhance the ability of designers to predict what the effective environment of people will be when the built environment is configured in a particular pattern" (Lang, 1987, p. 75). Dan Lockton added that by identifying these patterns and continuing to improve environment-behavior models, "the closer [it] comes to probabilism" (2012, p. 8).

As applied to this this study, probabilistic theory holds that one would expect objective measures of streetscape qualities related to walkability to help explain pedestrian activity, while controlling for important macroscale measures of walkability. In order to determine key variables and a protocol for modeling this relationship, and establish the hypotheses and expected findings of this study, a review of relevant literature was conducted and is detailed below in Section 2.3.

2.3 Review of Walkability Literature

As emphasized in Chapter 1, urban design researchers have become increasingly interested in measuring the built environment as a potentially important factor in accounting for pedestrian activity and other human behaviors. One of the most important and widely-cited measures of the built environment as it relates to pedestrian activity is walkability – the measure of how conducive a place is to walking and other pedestrian activity. As noted by Lee and Talen, "tools ranging from quantitative GIS-based assessment to subjective measures of the pedestrian experience are now enlisted in the effort to properly assess the environmental correlates of walking. Often there is a trade-off to be made between efficiency and accuracy, and researchers struggle to find the proper balance" (2014, pp. 368-369). In a struggle to find a proper balance in this study, this review focuses on two primary methods used to collect walkability measures of the built environment: (1) macroscale, GIS-based measures and (2) microscale, streetscape observations (or audits). Notably missing from this literature review (and this study) are perceived (self-reported) environmental measures, which have been commonly[13] used to collect data on how individuals perceive their built, social, and political environment in relation to pedestrian activity by way of interviews, self-administered surveys, or questionnaires. As noted in Section 5.3, a logical extension of this study would be to include interviews or questionnaires to better understand the individual motives and interests of local pedestrians as they relate to objective measures of pedestrian activity, microscale measures of streetscape qualities, and macroscale measures of walkability.

[13] In a review of the "state of the science" on measuring the built environment for physical activity, Brownson et al. noted that perceived (self-reported) environmental measures had been used in over 100 published studies and shown positive associations between pedestrian activity and perceived measures of recreation facilities, sidewalks, shops, and services (2009, p. S100). However, they also noted several trade-offs associated with using these measures, namely the difficulties in administration and declining response rates for all types of surveys (interview or questionnaires) (2009, p. S106).

As noted by Cain et al. (2014), measures of the built environment related to walkability fall into two broad categories – “macroscale” variables and “microscale” variables. The following review of the walkability literature briefly explains the progression of studies used to assess measures of the built environment as they relate to measures of travel behavior and pedestrian activity. This review of the walkability studies starts with a brief review of macroscale studies addressing the relationship between the built environment and pedestrian activity. It then explains in more detail the recent development of several walking audit instruments used to measure microscale factors of the built environment related to walkability. The gap in the knowledge regarding the specific measurement of perceptual streetscape qualities and their relationship to pedestrian activity is then highlighted and used to establish key hypotheses and expected findings of this study.

2.3.1 Macroscale Walkability Studies

Until recently, macroscale measures of the built environment related to walkability have formed the basis for much of the evidence describing the relationship between the built environment and pedestrian activity. As Millstein et al. noted, “[l]arger characteristics, often called macro-level attributes of environments (e.g., density, street connectivity, land-use mix) are well-documented correlates of walking and physical activity (Brennan Ramirez et al., 2006; Ross C. Brownson et al., 2009; Brian E. Saelens & Handy, 2008). Most of the built environment and physical activity evidence is based on macro-level variables" (2013, p. 1). Macroscale measures of walkability often include measures of neighborhood density, diversity, destination accessibility, distance to transit, and street network design, commonly referred to in the literature as "D variables[14]." Importantly, macroscale measures of the D variables (see Table 2) can be easily and objectively measured using reliable secondary data sources and geographic information systems (GIS) analysis tools (Ross C. Brownson et al., 2009). And, as noted by Ameli et al. (2015) and Ewing et al. (2015), macroscale measures have been used to characterize the walkability of built environments in over 200 studies.

However, macroscale measures alone may not fully explain a pedestrian's experience in a walking environment. That is, as Millstein et al. explained, there may be other, more microscale factors that "may also influence physical activity (Boarnet, Forsyth, Day, & Oakes, 2011; Ross C. Brownson et al., 2009;

[14] *D variables* was a term originally coined by Cervero and Kockelman (1997) to refer to measures of density, diversity, and street network design, and was later expanded to include additional measures such as destination accessibility and distance to transit (Ewing & Cervero, 2001, 2010).

Moudon & Lee, 2003) but have not been studied as extensively as macro-scale factors" (2013, p. 1).

Table 2 – Description of macroscale "D variables"

D Variable	Brief Description	Examples of Measurement
Density	Selected variable of interest (e.g., population) per unit of area (e.g., quarter-mile buffer)	Population density Job density Floor-area ratio
Diversity	Number of land uses (e.g., residential, commercial, etc.) per unit of area (e.g., quarter-mile buffer)	Land-use entropy Jobs-housing balance
Street Network Design	Street network characteristics in selected area (e.g., quarter-mile buffer)	Intersection (or street) density Percentage of four-way intersections
Destination accessibility	Ease of access to everyday amenities/attractions (e.g., shops)	Jobs, shops, etc. within quarter-mile
Distance to transit	Distance to transit stops (including bus, train, subway, etc.)	Average shortest distance to nearest bus, subway, etc. stop

2.3.2 Microscale Walkability Studies

Recently, several tools (or protocols), commonly known as walking audit instruments, have been developed for measuring the relationship between microscale factors of pedestrian environments and activity (see Table 3). Unlike macroscale measures related to walkability, walking audit instruments typically require direct, in-person observations of individual streetscape features, such as pavement coverage, building heights and setbacks, street widths, and block lengths. More recently, some researchers

Table 3 – Brief summaries of walking audit instruments/tools/studies[15] measuring microscale, streetscape factors of the built environment related to walkability

Instrument/Tool/Study	Brief Description	Reference(s)
Irvine-Minnesota Inventory (IMI)	Country of Origin: United States of America (USA) Factors included: 162 features/items, organized into four domains: accessibility, pleasurability, perceived safety from traffic, and perceived safety from crime Notes: The IMI was developed in 2003-2004. The inventory of 162 built environment features linked to active living (especially walking) was built by: (1) reviewing multidisciplinary literature on active living; (2) conducting three focus group interviews with lower-income persons, teens, and nonwhite college students; (3) field surveys by the authors of a variety (27) settings throughout the United States; and (4) a panel discussion with five experts from the fields of urban planning, health, GIS, and environmental psychology. All items included in the tool can be measured through in-person observation, noting the presence or absence of each streetscape feature. After being developed, the IMI was initially tested for inter-rater reliability by Boarnet et al. (2006), which indicated that a majority (76.8% in tests conducted by University of California-Irvine students and 99.2% in tests conducted by University of Minnesota students) of the features included in the inventory had >80% agreement between multiple raters. Tests were also conducted in the Twin Cities Walking Study (US) using the IMI to assess the predictive value of the IMI (Boarnet, Forsyth, et al., 2011). Results from this test indicated that only some (16) of the "themes" (e.g., street crossings, vertical mixed use buildings, distinctive retail, neighborhood identification, etc.) included in the inventory were associated with increased walking.	(Boarnet et al., 2006; Boarnet, Forsyth, et al., 2011; Day et al., 2006)

[15] The examples of walking audit instrument summarized and cited in Table 3 were drawn from past reviews by Ewing et al. (2015), Ross C. Brownson et al. (2009), and Moudon and Lee (2003). This table is not intended to be a comprehensive list of walking audit instruments, but does highlight key instruments/tools/studies used to measure microscale streetscape factors.

Instrument/Tool	Brief Description	Reference(s)
Analytic Audit Tool	Country of Origin: USA Factors included: 144 features/items, including measures of recreational facilities, physical disorder, signage, and social environment Notes: The analytic audit tool was developed in 2001-2002 based on a compilation of 36 audit tools (many of which were selected from a review conducted by Moudon and Lee, 2003) identified from peer-reviewed literature, the Internet, experts from the fields of transportation and health, and advocacy groups. The tool was used to conduct an audit of 147 street segments in St. Louis, MO (US), resulting in ≥ 75% agreement between two raters for 100% of reactional facilities variables (e.g., parks playgrounds, etc.) and 75% of land-use environment variables (e.g., restaurants, places of worship, etc.).	(Ross C Brownson et al., 2004)
Maryland Inventory of Urban Design Qualities (MI-UDQ) protocol	Country of Origin: USA Factors included: 27 features/items, organized according to best-fit models of five urban design qualities related to walkability, including imageability, enclosure, human scale, transparency, and complexity Notes: The MI-UDQ was developed in 2005 as the first and only (to the knowledge of the author) instrument to successfully operationalize several objective measures of urban design qualities (streetscape qualities) related to the walkability of streets. Further details on the development and preliminary applications of this protocol are provided in Sections 1.3, 1.4, and 2.3.2.1, as it was adapted, in collaboration with Prof. Reid Ewing, for use in this study – see Appendix D.	(Ameli et al., 2015; Clemente et al., 2005; Ewing & Clemente, 2013b; Ewing et al., 2005; Ewing et al., 2015; Ewing & Handy, 2009; Ewing et al., 2006)

Instrument/Tool	Brief Description	Reference(s)
Pedestrian Environment Data Scan (PEDS) tool	Country of Origin: USA Factors included: 47 features/items, organized into groupings of environmental, pedestrian facility, road and walking/cycling attributes Notes: PEDS tool was developed in 2004 based on the SPACES tool developed by T. J. Pikora et al. (2006) and designed to capture a range of built and natural environment elements using a handheld, personal digital assistant (PDA) device. Reliability tests were conducted during a study in College Park, MD (US) involving 12 trained undergraduate students and 192 street segments. Overall, most of the items measured (33 out of 47) had Kappa scores ≥ 0.4	(Clifton et al., 2007)
Active Neighborhood Checklist	Country of Origin: USA Factors included: 57 features/items, organized into sections including land use characteristics, sidewalks, shoulders and bike lanes, street characteristics, and quality of the environment for a pedestrian Notes: The Active Neighborhood Checklist was developed as a refined version of the Analytic Audit Tool developed by Ross C Brownson et al. (2004). A diverse (with regards to socioeconomic levels, urbanization, and land use) sample of 64 street segments were audited by a group of 15 public health researchers and seven community stakeholders in April 2005 following a two-hour training session. Interrater reliability was tested using observed agreement and Cohen K statistics for the items included in each section of the checklist. The mean observed agreement for 57 evaluated items was 0.87 (range, 0.61–1.00), and the mean K statistic was 0.68 (range, 0.21–1.00).	(Hoehner et al., 2007)

Instrument/Tool	Brief Description	Reference(s)
Physical Activity Resource Assessment (PARA) instrument	Country of Origin: USA Factors included: 97 “physical activity resources”, including parks, churches, schools, sports facilities, trails, etc. Notes: The single-page PARA instrument was developed over a period of nine months to assess publicly available physical activity resources in 13 lower-income, high ethnic minority neighborhoods and 4 higher-income, low ethnic minority neighborhoods in Kansas City, Kansas and Missouri with similar population densities and connectivity. Three trained field auditors (doctoral candidates in psychology) rated 97physical activity resources according to location, types, cost, features, amenities, etc. Results of the audits within each 800-meter neighborhood radius indicated that on average higher-income neighborhoods had more physical activity amenities, and qualities ranged from mediocre to good, with most resources accessible at no cost (82%). Reliability tests showed “good” reliability (r > 0.77).	(R. E. Lee, Booth, Reese-Smith, Regan, & Howard, 2005)
Scottish Walkability Assessment Tool (SWAT)	Country of Origin: Scotland Factors included: 48 features/items, organized into four categories: (1) functional, objective measures of streetscape features, and subjective evaluations of (2) safety, (3) aesthetics, and (4) travel destination (the relationship between residences and neighborhood services Notes: The SWAT was adapted from the SPACES tool (T. J. Pikora et al., 2002) and used to objectively assess physical features of the environment believed to be related to walkability in Scottish cities. Three pairs of trained raters audited 30 samples street segment on two separate occasions from across Glasgow’s Merchant City. 15 items had adequate variability and very good agreement (k > 0.7) and 18 items had adequate variability and good-fair agreement (0.4 ≤ k < 0.7). Only the 33 items with adequate variability and k4.4 for the inter-rater tests were included in the intra-rater reliability tests. Of these, 17 items had adequate variability and very good intra rater agreement (k >0.7).	(Millington et al., 2009)

Instrument/Tool	Brief Description	Reference(s)
Microscale Audit of Pedestrian Streetscapes (MAPS)	Country of Origin: USA Factors included: 160 features/items, organized into subscales including routes, segments, crossings, and cul-de-sacs Notes: The MAPS tool was developed based on several previous instruments, primarily the Analytic Audit Tool (Ross C Brownson et al., 2004), to assess individual streetscape features believed to be related to physical activity. Objective microscale environmental data was collected from MAPS sections (290 route pairs, 319 crossing pairs, and 53 cul-de-sac pairs) from urban neighborhoods in Seattle/King County, WA, San Diego, CA, and five counties in the Baltimore, MD-Washington, DC region. Of items included in the subscales, 80 items (50.0%) had good/excellent reliability and 41 items (25.6%) had moderate reliability. Individual inter-rater item reliability analyses were computed using Kappa, intra-class correlation coefficient (ICC), and percent agreement.	(Millstein et al., 2013)
Systematic Pedestrian and Cycling Scan (SPACES) instrument	Country of Origin: Australia Factors included: 67 features/items, organized into four categories: (1) functional, objective measures of streetscape features, and subjective evaluations of (2) safety, (3) aesthetics, and (4) travel destination (the relationship between residences and neighborhood services. Notes: SPACES was developed following consultation with experts from a variety of fields and a literature search as an observation-based audit tool focused on Australian cities. Spaces was used to collect data on over a total of 1987 kilometers of roads in Perth, Australia. Additional environmental information was collected using desktop methods and geographic information systems (GIS) technology. Inter- and intra-rater reliability of the instrument was assessed by 16 observers who collected the data. Reliability testing resulted in ≥ 75% agreement between two raters, and kappa statistics, K for 48 of the 67 items K ≥ 0.4.	(T. Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003; T. J. Pikora et al., 2002)

(e.g., Badland et al., 2010; Clarke et al., 2010) have also started exploring ways to virtually audit urban environments using Google Street View (Google Inc., 2016) and Bing Streetside (Microsoft, 2016).

Overall, despite the comparatively small number of studies, the literature on microscale streetscape features and their relationship to pedestrian activity is promising. In reviewing the state of the science on measuring the built environment for pedestrian activity, Brownson et al. found that many of the 20 walking audit instruments reviewed had been systematically developed and displayed high degrees of inter-rater reliability (2009). Pikora et al.'s study of the local neighborhood environments of 1,678 adults in Perth, Australia found that microscale features, such as well-maintained walking surfaces and the presence of destination factors on the street (including shops and public transport), were significantly ($p < 0.005$) correlated with self-reported measures of walking for transport (2006). Similarly, Boarnet et al.'s walkability study based on data collected from over 700 people and 891 street segments throughout the Twin Cities of Minneapolis and Saint Paul Minnesota (USA) found that microscale features such as the presence of sidewalks, pedestrian crossings, destination factors (including gathering places, playing fields, and plazas), and traffic calming were significantly($p < 0.05$) associated with pedestrian activity (2011).

However, while showing some promise, Bauman et al. have argued that there are still not enough studies using microscale factors to support conclusions about the relationship between microscale streetscape measures and pedestrian activity (2012). Moreover, Cain et al. added, "[t]he literature is further limited by inconsistent definitions and scoring…and failure to control for macroscale attributes" (2014, p. 83). And, Ewing and Clemente warned that "[p]hysical [streetscape] features individually may not tell us much about the experience of walking down a particular street. Specifically, they do not capture people's [sic] overall perceptions of the street environment" (2013, p. 2). Given these deficiencies in the literature, there is a need to further explore the specific relationship between streetscape qualities and pedestrian activity, using objective and validated measures of streetscape qualities and controlling for important macroscale measures of walkability.

2.3.2.1 Microscale Studies of Streetscape Qualities Related to Walkability

The importance of perceptual streetscape qualities and their relationship to pedestrian activity has been written about extensively in the urban design literature (e.g., Cullen, 1961; Gehl, 1987; A. Jacobs, 1993; A. Jacobs & Appleyard, 1987; J. Jacobs, 1961; Lynch, 1960; Rapoport, 1990; Sitte, 1889; Whyte, 1980). However, as noted by Ewing and Handy (2009), there remains a surprising lack of empirical evidence in support of these claims based on validated, objective measures of streetscape qualities.

As covered in greater detail in Section 1.3 above, only a handful of recent studies have attempted to address this gap in the research. To briefly summarize again here, the first of these studies established the first operational definitions and measurement protocols for five streetscape qualities related to walkability, including imageability, enclosure, human scale, transparency, and complexity (Clemente et al., 2005; Ewing et al., 2005; Ewing & Handy, 2009; Ewing et al., 2006). While each of the five streetscape qualities met strict operationalization criteria, only limited field studies were conducted at the time to test for further validation of the measures.

Subsequently, two preliminary field studies have been conducted based on the objective definitions of streetscape qualities and measurement protocols operationalized in these previous studies. The first of these studies used measurements of the five streetscape qualities and pedestrian counts from 588 street segments in New York City (Ewing & Clemente, 2013c; Neckerman et al., 2013) and found that streetscape qualities significantly ($p \leq 0.05$) improved the explanatory power of walkability models, and that measures of transparency, in particular, were directly and significantly related ($p \leq 0.05$) to pedestrian activity, when controlling for macroscale measures of walkability.

Following this study, Ameli et al. (2015) conducted a similar, smaller-scale study on 179 street segments in the downtown "Free Fare Zone" area of Salt Lake City (SLC) using the same protocol. Ameli et al. also found that their walkability models were also significantly ($p \leq 0.05$) improved with the addition of streetscape qualities, and both transparency and imageability were significantly ($p \leq 0.05$) and directly related to measures of pedestrian activity, while controlling for macroscale measures of walkability. However, these preliminary field studies were not without limitations.

As discussed above in Section 1.4, the results for the New York City (NYC) study were limited in terms of their generalizability to other cities, as NYC represents one of American's most walkable and compact cities. As a suggestion for further research, Ewing and Clemente commented that future studies using the protocol should be conducted in "more typical cities" (Ewing & Clemente, 2013c, p. 98). The study by Ameli et al. was similarly limited in terms of generalizability of results by its relatively small sample size (n = 179 street segments) and narrowly-focused study area (downtown SLC). Ameli et al. (2015) suggested that future studies using the same protocol should include larger sample sizes and be conducted in study areas with more diversity of urban design and form.

Secondly, the reliability of the average pedestrian counts in the New York City study was limited by the relatively small number of counts and lack of standardization. Ameli et al. overcame this limitation by standardizing longer pedestrian counts (30-minutes per sample street segment) to get a more representative sampling of typical, weekday activity on the street. However, while this form of standardization may have worked well for a study with a more limited number of sample street segments and a team of field researchers, its application in larger, city-wide study areas with a single observer is not feasible.

Lastly, while both of these studies used in-person audits of streetscape qualities, the value of the protocols developed by Ewing et al. (2005) are likely to be extended by the implementation of improved virtual tools for data collection and analysis. Some work has already been done to improve methods for assessing features of the Ewing et al. (2005) protocol using virtual auditing techniques (Bader et al., 2015). However, these methods rely strictly on the use of Google Street View, which is limited in terms of its ability to capture all relevant streetscape features, temporal variability in the images, and data availability across the entire study area. Thus, there is still scope to extend the implementation of the Ewing et al. (2005) protocols by exploring new methods for virtual data collection and analysis.

2.4 Hypotheses and Expected Findings

The primary purpose of this study was to improve upon the limitations of past studies and better understand the relationship between streetscape qualities and pedestrian activity. Based the limited results from two preliminary studies (Ameli et al., 2015; Neckerman et al., 2013), the following hypotheses and expected findings were established at the start of this study:

1. Collectively, measures of the streetscape qualities add significantly ($p \leq 0.05$) to the overall explanatory power of the walkability models, when controlling for macroscale measures of walkability (i.e., measures of important D variables).

2. Individually, measures of streetscape qualities are directly and significantly ($p \leq 0.05$) related to average pedestrian counts (dependent variable), when controlling for macroscale measures of walkability (i.e., measures of important D variables).

3. Measures of streetscape qualities are of equal or greater significance in explaining measures of pedestrian activity, when compared to other known built environment correlates of pedestrian activity –i.e., macroscale measures of walkability (D variables).

By putting these hypotheses to the test and addressing the limitations of previous studies, this study addresses an important gap in research and ultimately works towards a better understanding how perceptual streetscape qualities may contribute to the design of streets as places for pedestrian activity.

CHAPTER 3. DATA AND METHODOLOGY

3.1 Introduction

The focus of Chapter 3 is the causal-comparative research design[16] used to examine the relationship between perceptual streetscape qualities and pedestrian activity. This chapter is divided into several sections, detailing both the data and methodology used in this study, in addition to describing relevant limitations and ethical considerations.

The first section of this chapter briefly describes the case study location – the City of Glasgow – and why it was selected for analysis. Glasgow is a typical post-industrial European city with a diversity of architecture and urban design qualities (Frey, 2004). It is also a city that has shown a strong commitment to improving the qualities of its built environments through

[16] Causal-comparative research designs seek to find relationships between groups of independent, control, and dependent variables. As noted by Brewer and Kuhn, "[t]he researcher's goal is to determine whether the independent variable[s] affected the outcome, or dependent variable, by comparing two or more groups" (2010, p. 124). In this study, two groups of results (or models) were compared: (1) a model containing only the control variables (D variables) and dependent variable (pedestrian activity), and (2) a model containing both the control and independent variables (streetscape qualities) and the dependent variable. See Chapter 4 for full details of the results and model comparisons.

design, technology, and a wealth of open source data (Glasgow Centre for Population Health, 2014; National Health Service Greater Glasgow and Clyde, 2006; Riddell, 2014). For these reasons, Glasgow was selected as an instrumental case[17].

The second section of this chapter describes the method used for establishing the units of observation within the case study area. A purposive sampling technique[18] was used to select the most central, pedestrian street segments from within each of the 694 Scottish Index for Multiple Deprivation (SIMD) datazones[19] across the city. This was done in order to obtain a representative sampling of the various streetscape qualities present throughout the city, while also ensuring that the samples were: (1) collected from streets segments that could accommodate pedestrian activity and (2) were likely to attract pedestrian activity due to their connection with the rest of the city.

---

[17] An instrumental case is "one that lends itself to the understanding of an issue or phenomenon beyond the case itself" (Putney, 2010, p. 116).

[18] Purposive sampling is a nonprobability sampling method that approaches the problem of collecting samples with a specific plan in mind (Trochim, 2006) – i.e., purposive samples are "collected on a predetermined criteria related to the research" (Hussey, 2010, p. 923)

[19] The terms *datazone* and *data zone* are used interchangeably in the literature. For consistency, *datazone* was used throughout this thesis.

The third section of this chapter details the primary and secondary data sources used in this study. It includes descriptions of the independent variables (streetscape qualities), control variables (D variables), and dependent variable (pedestrian activity). Brief descriptions of the variables are provided, including descriptive statistics and details of the best-fit models used to compute each of the streetscape qualities from unique combinations of measurable streetscape features.

The fourth section of this chapter describes the methodology used to collect the primary field data for computing the independent variables (streetscape qualities) in this study. Primary field data was collected using an innovative and validated video recording method and later analyzed using an updated and locally-adapted index of streetscape features and best-fit models.

The final section of this chapter briefly describes additional ethical considerations made during this study with regards to the collection of primary field data. Reference to the University of Strathclyde ethics approval and risk assessment forms is also provided.

3.2 Case Study Location

This case study analysis concentrates on the local authority of Glasgow City[20]. Glasgow is a city located in Scotland's West Central Lowlands, straddling the River Clyde to the north and south (see Figure 2).

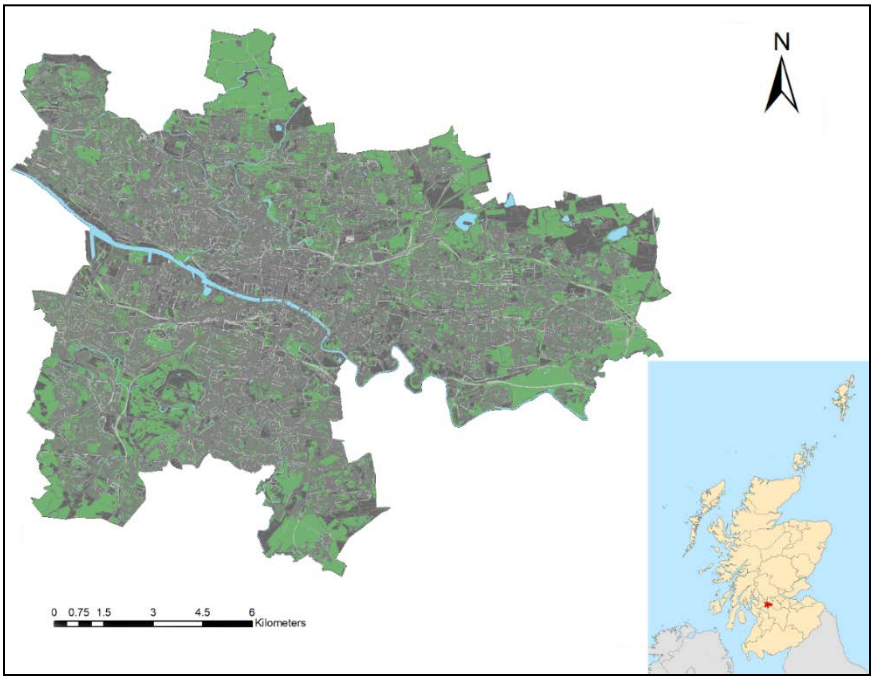


Figure 2 – Map of the local authority of Glasgow and its location within Scotland (Contains Ordnance Survey data © Crown copyright and database right, 2015)

The local authority covers an area of approximately 175 square kilometers (km^2) (Scottish Government, 2015) and is the largest by population (596,550

[20] The local authority of Glasgow City is simply referred to as *Glasgow* throughout this thesis. These terms are meant to be interchangeable and synonymous with the Scottish council area known as the City of Glasgow.

people) of any in Scotland[21] (National Records of Scotland, 2014) and third largest in the United Kingdom (UK)[22] (Office for National Statistics, 2015).

Glasgow is a city known not only for its diversity of architecture and urban design (see Appendix A), but also its spatial-formal cohesion in the historical areas of the city that have escaped comprehensive redevelopment (Frey, 2004)[23].

However, Glasgow also exhibits many adverse characteristics typical of post-industrial European cities, including sprawl, car-dependency, and social stratification (see Figure 3), and suffers from lower levels of physical activity and unexplained poor health (Glasgow Centre for Population Health, 2014; Reid, 2011). As a result, Glasgow is deeply committed to addressing these issues by improving the quality of its built environments and making smart use of technology to generate open-source datasets to better understand how

---

[21] At a population density of roughly 3,400 people per km^2 (per/ km^2), Glasgow is also the most densely populated city in Scotland (Office for National Statistics, 2014).

[22] Urban, or built-up areas (e.g., Greater London), are not always synonymous with the geographies of local authorities and are often comprised of several local authorities. There are 426 local authorities in the UK: 346 in England and 22 in Wales, referred to as local authorities; 32 in Scotland, referred to as council areas; and 26 in Northern Ireland, referred to as local government districts.

[23] For a more comprehensive history of Glasgow's historical development and relevant characteristics, detailed accounts are covered in several other works, including Horsey (1990), Reed (1999), and Frey (2004, Chapter 4).

the city functions in relation to pedestrian activity (Irwin, 2013; Riddell, 2014). It is the combination of the abovementioned characteristics and availability of data that make Glasgow particularly attractive for this study.

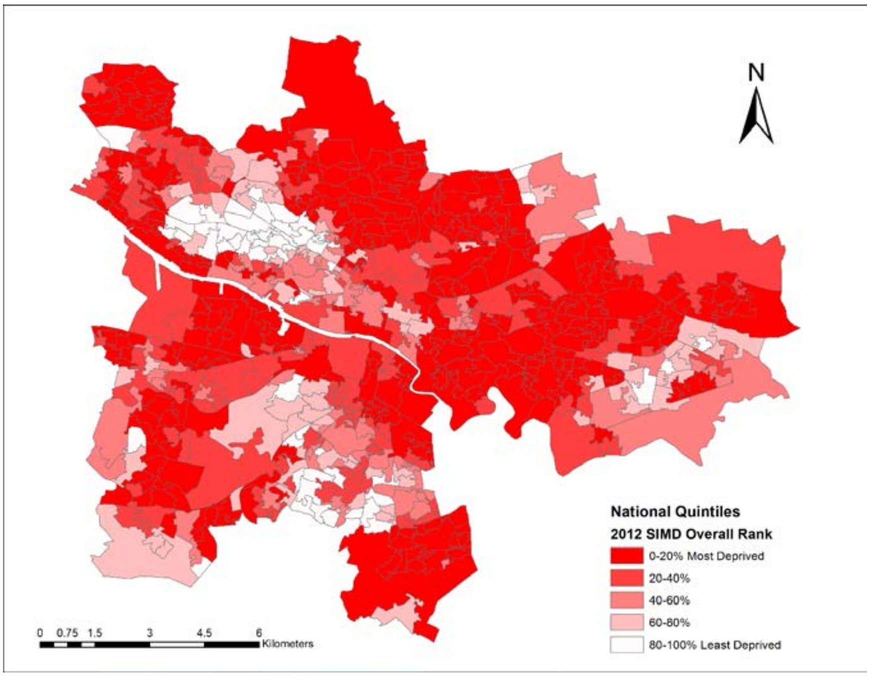


Figure 3 – Map of the 2012 Scottish Index of Multiple Deprivation (SIMD) overall rankings[24] for the datazones in Glasgow by national quintile (Contains Ordnance Survey data © Crown copyright and database right, 2015)

3.2.1 Note on the Author and the Case Study Location

Glasgow is also a city in which the author has lived over the past several years as a postgraduate student at the University of Strathclyde's Urban Design Studies Unit (UDSU, 2015). This position allowed for a unique, first-

[24] Scotland contains 6,505 SIMD datazones, rankings from 1, the most deprived, to 6,505, the least deprived. Glasgow contains 694 SIMD datazones, including some of the most and least deprived in all of Scotland, ranging from 2 to 6,480.

hand perspective on the range of streetscape qualities present throughout the city and access to local expertise and resources. Acquaintance with the city also facilitated the collection of primary field data and secondary GIS data during the study, and allowed additional observational assessments to be made.

3.2.2 Limitations of the Case Study Location

Glasgow is unique amongst cities in Scotland and throughout the rest of the UK. As noted by others (e.g., Neckerman et al., 2013), there are some limitations to the external validity or generalizability of findings from case-specific studies. However, because Glasgow is representative of a typical, post-industrial European city, it is hoped that as an instrumental case the results from this study might be used in future comparisons to studies conducted in similar types of cities.

3.3 Units of Observation

Central, pedestrian street segments were used as the units of observation in this case study analysis in order to: (1) obtain a representative and diverse sampling of the streetscape qualities present throughout the city, and (2) ensure that samples were collected from streets likely to attract pedestrian activity. As noted by Brownson et al., street segments are the typical units of observation for measuring built environment features at the sub-city scale when it is not feasible to audit the entire study area (2009). Street segments commonly measure the length of one city block and are comprised of two opposing street fronts (see Figure 4).

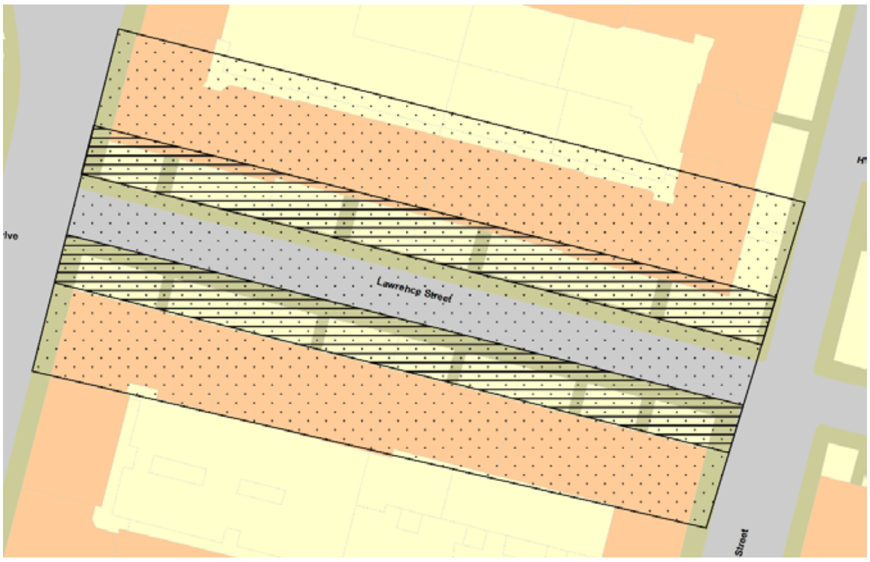


Figure 4 – Example of typical street segment (dotted area) with two opposing street fronts (hatched areas) (Contains Ordnance Survey data © Crown copyright and database right, 2015)

Street segments within a given study area can either be selected at random or using nonprobability sampling techniques to ensure that unique but important features or qualities are captured in the dataset. A nonprobability sampling method was developed for this study after a period of consultation with local experts (see Appendix B for brief biographies). Experts included academics and professionals from both the private and public sectors and were selected based on their expertise in urban design and knowledge of the case study area. When asked to suggest a method for acquiring a representative and diverse sampling of the streetscape qualities present across the city for use in this study, the experts proposed a method for sampling that involved auditing the most central street segment from within each of the 694 SIMD datazones within the city. This was suggested based on two primary assumptions: (1) streetscape qualities were likely to vary with changes in overall neighborhood characteristics, such as those measured by the SIMD (e.g., income, employment, housing, etc.), as shown in previous studies (e.g., Neckerman et al., 2013); and (2) central street segments are likely to attract pedestrian activity due to concentration of service and commercial activities, and their connection to the rest of the city, as also indicated in previous studies (e.g., Ozbil, Peponis, & Stone, 2011; Porta, Latora, et al., 2008).

3.3.1 Centrality Analysis

In order to determine the most central, pedestrian street segments from within each of the SIMD datazones, a centrality analysis was conducted using geographic information systems (GIS) on Glasgow’s street network.

Centrality analysis works by reducing streets networks to segments and nodes that can then be analyzed according to various indices of centrality (e.g., betweenness, closeness, straightness). There are two primary forms of centrality analysis: (1) dual graph representation, where street segments become nodes and points of intersection or endpoints become edges; and (2) primary graph representation, where street segments are represented as edges and points of intersection and endpoints are represented as nodes (Crucitti, Latora, & Porta, 2006; Porta, Crucitti, & Latora, 2006a, 2006b).

A primal graph representation method was used in lieu of a dual graph representation in order to retain the metric distance between nodes and allow for easier interpretation of results. The Multiple Centrality Assessment (MCA) tool for GIS that was developed and tested by Sergio Porta and colleagues (Porta, Crucitti, & Latora, 2008; Porta, Latora, et al., 2008; Wang, Antipova, & Porta, 2011) utilizes a primal graph representation method and was used to compute centrality measures for each of the 28,247 street segments across the entire city (see Figure 5). A 5 kilometer buffer was used in this case to account for edge effects that threatened to produce lower values around the boundaries of the local authority if cropped. As noted by Porta et al., an edge effect is "a typical distortion of the spatial distribution on

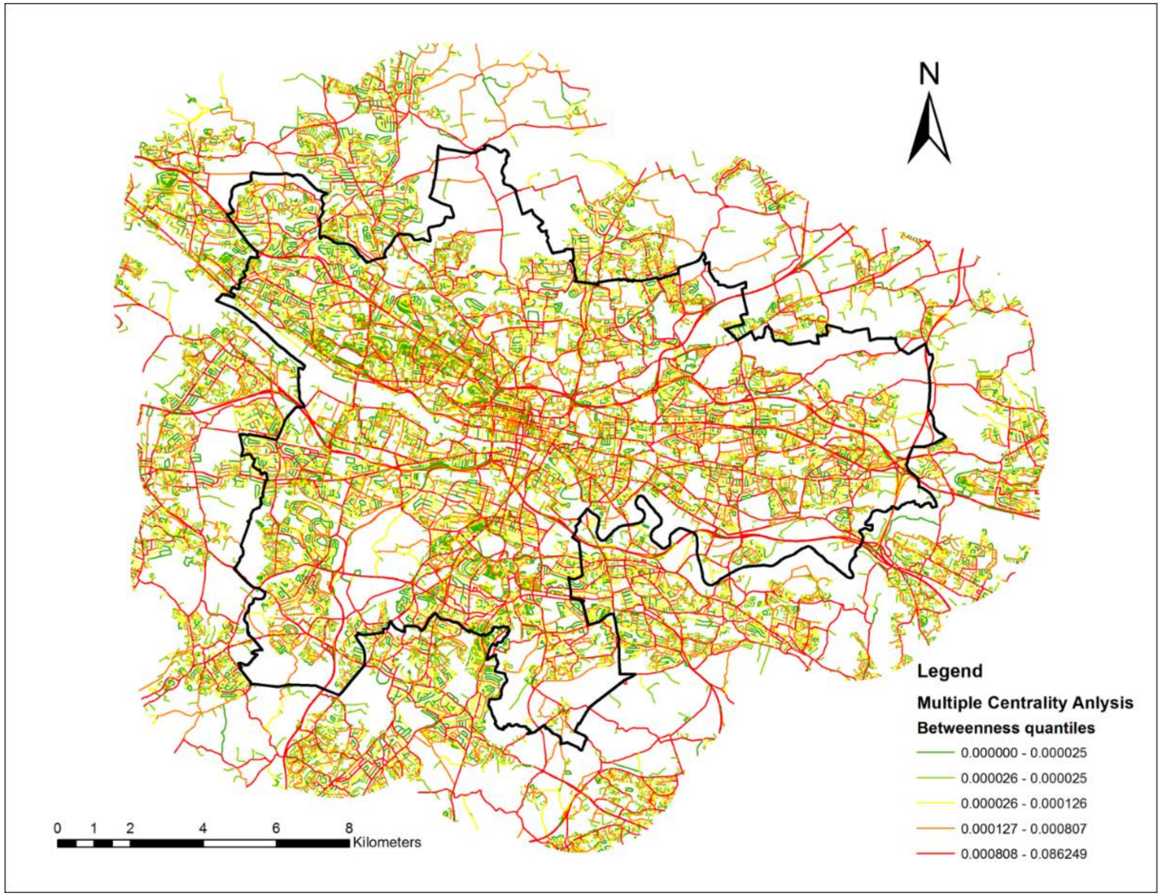


Figure 5 – Betweenness centrality of 28,247 street segments in Glasgow with 5 km buffer (Contains Ordnance Survey data © Crown copyright and database right, 2015)

centrality values that artificially groups the highest scores around the centre [sic] of the image no matter the actual configuration of the network (Ratti, 2004; Salheen & Forsyth, 2001)" (Porta, Crucitti, et al., 2008, p. 42).

As opposed to other centrality metrics (e.g., closeness or straightness), the betweenness metric was used as the primary measure of street centrality in this study because of its theoretical connection to pedestrian activity and travel behavior. As Andres Sevtsuk noted, "[it] can be intuitively thought of as the potential amount of traffic on each street segment that results if one person were to travel from each intersection to each other intersection in the given road network along the shortest paths" (2010, p. 44). Betweenness centrality is defined as "the degree to which a point falls on the shortest path between others and therefore has a potential for control of communication" (Freeman, 1977, p. 35). In order to calculate the betweenness value of a given street segment, a matrix of shortest-path connections must first be calculated for all nodes in the system. Then, a betweenness value for each node, i, can be calculated as the number of times that the node is traversed in this matrix of shortest paths.

Betweenness was defined mathematically by Crucitti et al. (2006) and Porta, Latora, et al. (2008) as:

$$Betweenness_i = \frac{1}{(N-1)\,(N-2)} \sum_{j=1;k=1;j\neq k\neq i}^{N} \frac{n_{j,k}(i)}{n_{j,k}}$$

where *N* is the number of nodes in the system, $n_{j,k}$ is the number of shortest paths between nodes *j* and *k*, and $n_{j,k}(i)$ is the number of these shortest paths that contain node *i*. According to Porta et al., when applied to urban street networks a betweenness centrality value is a "special property for a place in a city: it does not act as an origin or a destination for trips, but as a pass-through point. C^B [betweenness centrality] represents a node's volume of through traffic" (2008, p. 453).

After computing the measures of betweenness for each of the street segments throughout the city, this layer of data was then intersected with the boundaries of the SIMD datazones to determine the most central street segments from within each datazones (see Figure 6). Street segments were then pre-screened to meet two additional requirements: (1) a minimum length of 50 meters (m), the typical length of a small city block in Glasgow; and (2) the presence of pavement, ensuring that the sample street segment was able to accommodate pedestrian activity. When these conditions were not met (e.g., when the most central street segment was identified as a

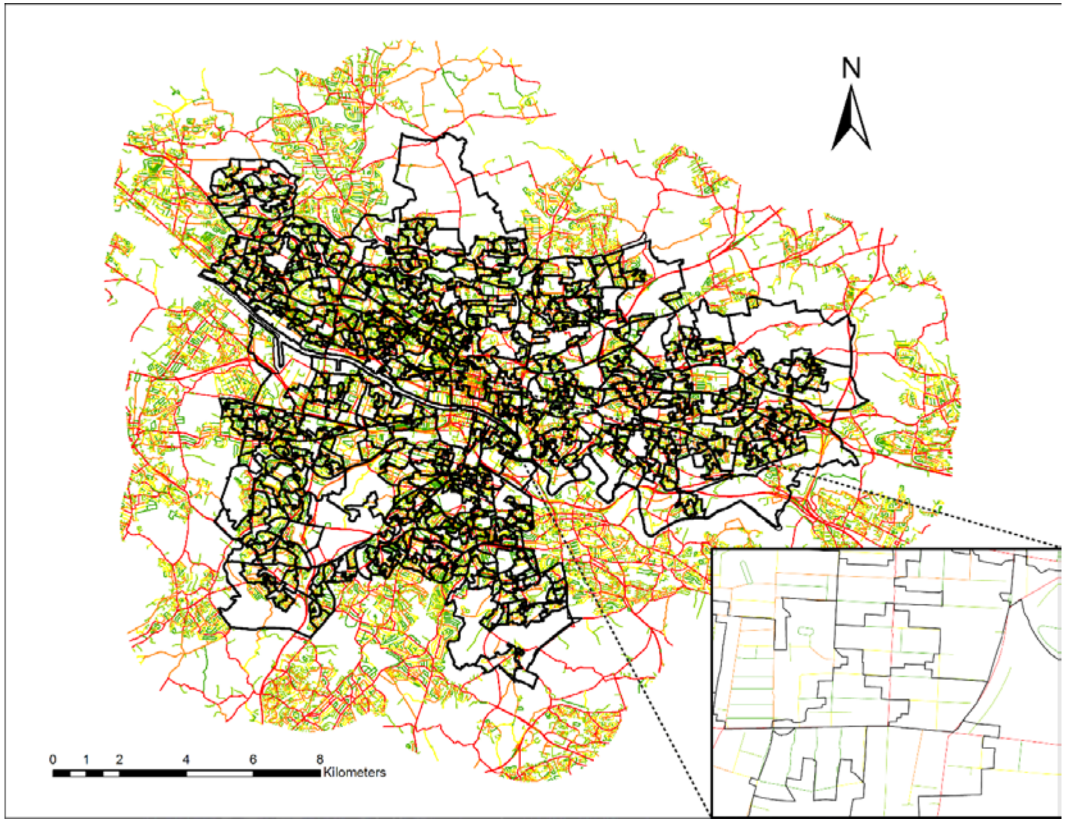


Figure 6 – Betweenness of street segments in the 694 Glasgow SIMD datazones (Contains Ordnance Survey data © Crown copyright and database right, 2015)

motorway segment), the next most central street segment within the same datazone was screened until a suitable selection could be made.

In some instances, even the most central, pedestrian street segment was not observable due to obstructions in the field (e.g., local construction) during primary data collection. In these situations, every effort was made to revisit the sample street segment at a later point in time to avoid obstructions. However, when this was not feasible, the next most central pedestrian street segment within the same datazone was audited during the sampling period. Only in one instance was there a datazone (datazone code: S01003533) with no observable pedestrian street segments during the entire sampling period due to local demolition around the Red Road Flats. Therefore, there are 693 data points in the dataset as opposed to 694.

3.3.2 Limitations of the Units of Observation

The method for selecting the units of observation, as mentioned above, was limited by the fact that it focused strictly on those street segments deemed most central within each of the SIMD datazones. This makes it difficult to generalize results of this study to the rest of the streets throughout each of the SIMD datazones, let alone the city as a whole. However, this method was used in lieu of a randomized selection, in an attempt to capture relevant and unique sample street segments (e.g., Buchanan Street, Great Western Road, London Road, etc.) that were most likely to attract pedestrian activity and be of the greatest importance to the local population due to the connection with the rest of the city.

3.4 Data

Primary data for this study was collected from 693 sample street segments from within the study area over the course of two summers, 2014 and 2015, using the methodologies described in Section 3.5, Appendix C, and Appendix D[25]. This data was used to generate the independent variables (streetscape qualities) and dependent variable (pedestrian activity) for each sample street segment included in the dataset. Secondary data was acquired directly from the EDINA Digimap Ordinance Survey Service, the Glasgow OPEN Data Launchpad[26], the Scottish Government, and other sources (see Table 4). Efforts were made to only use secondary data that was readily available in other parts of the country in order to make the process of data collection as replicable as possible in other cities throughout Scotland and

[25] In order to limit the text included in the main body of this chapter, the methodology explained in Section 3.5 is limited to details on the sampling criteria, pilot test results, and reliability test results. Appendix C and Appendix D provide more specific details on the video recording protocol used for primary data collection and the field manual used for auditing each sample street segment, respectively.

[26] Glasgow OPEN Data Launchpad (link): https://data.glasgow.gov.uk/

Table 4 – Table of secondary data types, uses, and sources

Data Type	Use	Dataset source (License)
Building heights	Used to compute floor area ratios	OS MasterMap Topography Layer - Building height attribute (BHA) (OS Digimap License)[1]
Road centerlines	Used to compute betweenness centrality, intersection density, proportion of 4-way intersections, and distance to transit	OS MasterMap Integrated Transport Network (ITN) (OS Digimap License)[2]
Subway locations	Used to compute distance to transit	Glasgow Subway Station Locations (Glasgow City Council Ordnance Survey Development Data License)[3]
Bus stop locations	Used to compute distance to transit	National Public Transport Access Nodes (NaPTAN), Bus Stop Locations (Open Government License)[4]
Rail station locations	Used to compute distance to transit	NaPTAN, Rail Station Locations (Open Government License)[4]
Census data	Used to compute population densities and household size	Scotland Census Data Warehouse (Open Government License)[5]
Building footprints	Used to compute floor area ratios and land use entropy	OS MasterMap Topography Layer (OS Digimap License)[6]
Land uses	Used to compute land use entropy	OS AddressBase Premium (OS Research Data Agreement)[7]
Datazones	Used to create boundaries for the study area	Scottish Government - Data Zone Boundaries 2011 and Scottish Government - Data Zone Centroids 2011 (Open Government License)[8]
Walkability	Used to compute destination accessibility	Walk Score[9]

[1]OS MasterMap Building Heights Layer [GML geospatial data], Ordnance Survey, Using: EDINA Digimap Ordnance Survey Service, http://digimap.edina.ac.uk/
[2]OS MasterMap ITN Layer [GML geospatial data], Ordnance Survey, Using: EDINA Digimap Ordnance Survey Service, http://digimap.edina.ac.uk/
[3]Glasgow City Council Ordnance Survey Development Data License: http://open.glasgow.gov.uk/ckansupport/oGCC_OS_Developer Data Licence.pdf
[4]Open Government License: http://reference.data.gov.uk/id/open-government-licence
[5]Scotland Census Data Warehouse (link): http://www.scotlandscensus.gov.uk/ods-web/data-warehouse.html
[6]OS MasterMap Topography Layer [GML geospatial data], Ordnance Survey, Using: EDINA Digimap Ordnance Survey Service, http://digimap.edina.ac.uk/
[7]OS AddressBase Premium (link): https://www.ordnancesurvey.co.uk/business-and-government/products/addressbase-premium.html
[8]Scottish Government - Data Zone Boundaries and Centroids 2011 (link): http://sedsh127.sedsh.gov.uk/Atom_data/ScotGov/StatisticalUnits/SG_StatisticalUnits.atom.en.xml
[9]Walk Score (link): https://www.walkscore.com/

rest of the UK. This data was used in conjunction with GIS software to compute the control variables (D variables) related to density, diversity, street network design, destination accessibility, distance to transit, and demographics.

3.4.1 Independent Variables (Streetscape Qualities)

The explanatory variables of primary interest in this study were the five streetscape qualities related to walkability that were previously operationalized by Ewing et al. (Ewing et al., 2005; Ewing et al., 2006) and later used in preliminary studies conducted in two US cities, New York City (Neckerman et al., 2013) and Salt Lake City (Ameli et al., 2015). The streetscape qualities measured included imageability, enclosure, human scale, transparency, and complexity. Each of these qualities is rooted in classic urban design theory and comprised of unique groupings of streetscape features. Brief qualitative descriptions of the streetscape qualities, along with operational definitions and quantitative best-fit models used to operationalize these variables, are provided in the sections below.

3.4.1.1 Note on Best-Fit Models for Independent Variables (Streetscape Qualities)

As summarized above in Section 1.3 and Section 2.3.2.1, and explained in greater detail in related reports and publications (see Ewing & Clemente, 2013b; Ewing et al., 2005; Ewing et al., 2006), the best-fit models for each of the streetscape qualities used in this study were based on previous ratings by an expert panel of urban design and public health researchers and used to operationalize each streetscape quality based on a set of measurable streetscape features. Operationalization of each streetscape quality was based on several criteria: (1) if the streetscape quality had no correlation to overall walkability (i.e., the null hypothesis was true), the probability of a type 1 error[27] (α) was less than or equal to 5 in 100 (i.e., $p \leq 0.05$); (2) the degree of agreement among independent, expert panel raters (i.e., inter-rater reliability) in measuring the quality was at least "moderate" according to the relative strengths of agreement suggested by Landis and Koch (1977)[28] (intra-class correlation coefficients, ICC ≥ 0.4); (3) measurable streetscape features accounted for 30 percent or more of the total variance in ratings of the quality; (4) measurable streetscape features explained 60 percent or more of the sample-specific variance in ratings of the quality; and (5) all streetscape

[27] Commonly referred to as a "false positive."
[28] See Page 11 for note on benchmarks.

features related to ratings of the quality were measured with at least a "moderate degree of inter-rater reliability (ICC ≥ 0.4).

These best-fit models were adapted slightly from those presented initially in Ewing et al. (2005) and later revised in Ewing and Clemente (2013b), as there were some slight differences between the two models. After a period of consultation with Professor Reid Ewing (University of Utah) and colleagues, more accurate re-estimations of the best-fit models were provided.

In order to compute the scores for each of the five streetscape qualities used in this study, field measures of the streetscape features for each sample street segment were inserted into the re-estimated best-fit models (shown in the sections below) with the two notable modifications. The best-fit models from Ewing et al. (2005) and Ewing and Clemente (2013b) for imageability and complexity originally included the variable *"number of people"* encountered while walking the sample street segment. This feature was instead used in this study as the dependent variable; therefore, it was excluded from the calculation of these two independent variables (streetscape quality).

3.4.1.2 Imageability

Imageability is a term that was first coined by Kevin Lynch as "that quality in a physical object which gives it a high probability of evoking a strong image in any given observer. It is that shape, color, or arrangement which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment" (Lynch, 1960, p. 9). The quality of imageability may also be referred to as *legibility* and is closely related to Gordon Cullen's concepts of *Here and There* or *This and That* (Cullen, 1961), which asserts that a sense of place is achieved when townscape elements are designed as part of a cohesive whole. As Jan Gehl briefly summarized:

> *"This feeling of spatial quality characterizes many old pedestrian cities and spaces. In Venice, for example, and in many famous Italian city squares, life in the space, the climate, and the architectural quality support and complement each other to create an unforgettable total impression. When all factors have the opportunity of working together as in these examples, a feeling of physical and psychological well-being results: the feeling that a space is a thoroughly pleasant place to be in." (1987, p. 183).*

Landmarks are one type of streetscape feature believed to be essential to the quality of imageability. A landmark can be used as a focal point, contrasting elements to attract attention, which as Tunnard and Pushkarev argued, “lifts a considerable area around itself out of anonymity, giving it identity and visual structure” (1963, p. 140). Landmarks range in scale from distinct buildings, parks, and plazas to unique building features like domes and signs. Ultimately, “[l]andmarks become more easily identifiable, more likely to be chosen as significant, if they have a clear form; if they contrast with their background; and if there is some prominence of spatial location” (Lynch, 1960, pp. 78-79).

Imageability was previously defined by Ewing and Handy (2009) and referred to in this study, as: “the quality of a place that makes it distinct, recognizable and memorable” (p. 73). A streetscape with high imageability contains specific physical elements that are arranged to capture attention, evoke feelings, and create a lasting impression. Table 5 shows the best-fit model of the streetscape features used to compute scores for imageability in this study.

Table 5 – Best-fit imageability model

Variable	Coefficient	p-value
Constant	2.516	-
Proportion of historic buildings	0.970	0.001
Number of courtyards, plazas, or parks	0.414	0.001
Presence of outdoor dining	0.644	0.001
Number of buildings with non-rectangular silhouettes	0.0795	0.036
Noise level (1-5 Likert scale)	-0.183	0.045
Number of major landscape features	0.722	0.049
Number of buildings with identifiers	0.111	0.083

All of these streetscape features in the best-fit model have positive relationships to perceptions of imageability with the exception of noise level, which has a negative relationship and thus diminishes the quality. Figure 7, Table 6, and Table 7 show the frequency distribution and descriptive statistics for imageability measures from all 693 sample street segments included in the dataset. Overall, imageability scores were positively skewed and non-normally distributed, with scores ranging from 1.71 to 7.68 and a mean ± standard deviation of 3.12 ± 1.01.

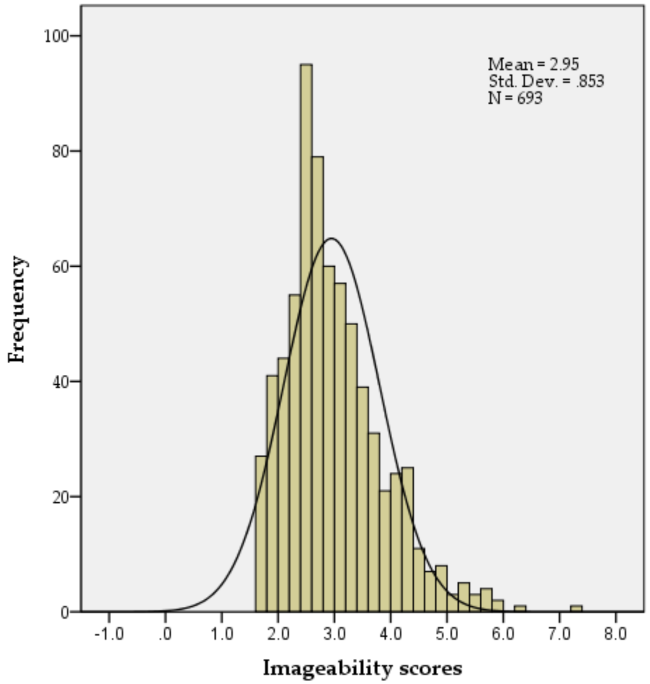


Figure 7 – Histogram of the imageability scores

Table 6 – Decriptive statistics of the imageability scores

	N	Min	Max	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
Imageability Scores	693	1.7	7.2	2.95 ± 0.85	0.73	1.05 ± 0.09	1.43 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 7 – Shapiro-Wilk test of the imageability scores

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.93	693	7.99E-17

3.4.1.3 Enclosure

Enclosure is a quality used to "define" streets (A. Jacobs, 1993, pp. 277-281) or describe the room-like quality of outdoor, urban environments, created by vertical elements like buildings, walls, and trees (Alexander et al., 1977, pp. 764-768; Sitte, 1979, pp. 20-24). According to Gordon Cullen, "[e]nclosure, or the outdoor room, is, perhaps, the most powerful, the most obvious, of all the devices to instill a sense of position, of identity with the surroundings." (Cullen, 1961, p. 29). Allen Jacobs and Donald Appleyard explained , "[i]n an urban environment, buildings (and other objects that people place in the environment) should be arranged in such a way as to define and even enclose public space, rather than sit in space" (1987, p. 118). Outdoor rooms are formed when buildings or other vertical elements form the walls, streets and pavements make up the floor, and the sky acts as a ceiling. Alexander et al. (1977, p. 518) stated that, "[a]n outdoor space is positive when it has a distinct and definite shape, as definite as the shape of a room, and when its shape is as important as the shapes of the buildings which surround it." Hedman and Jaszewski (1984) echoed these remarks, asserting "[i]f the quality of three-dimensional space and not just the functional use of the ground surface becomes important, then the designer's concern graduates to an entirely different level that involves the architectural characteristics of the building facades and how they work to create a three-dimensional sense of space…Such intense three-dimensional space offers a positive sensory experience" (pp. 53-54).

Enclosure was previously defined by Ewing and Handy (2009) and referred to in this study, as: "the degree to which streets and other public spaces are visually defined by buildings, walls, trees and other vertical elements" (p. 75). Table 8 shows the best-fit model of the streetscape features used to compute scores for enclosure in this study.

Table 8 – Best-fit enclosure model

Variable	Coefficient	p-value
Constant	2.570	-
Proportion of street wall (same side)	0.716	0.001
Proportion of street wall (opposite side)	0.940	0.002
Proportion of sky across	-2.193	0.021
Long sight lines	-0.308	0.035
Proportion of sky ahead	-1.418	0.055

Long sight lines and larger proportions of visible sky are streetscape features that have a negative relationship to enclosure, while more continuous street walls on both sides of the street segment positively contribute to perceptions of enclosure. Previous studies have also shown that perceptions of enclosure are positively correlated to the portion of a street scene covered by walls and negatively related to the proportion of a street scene covered by ground, depth of view, and the number of sides open at the street front (Stamps, 2005; Stamps & Smith, 2002).

Though features like building setbacks were originally intended to have a positive effect by bringing more light and air to the street, some urban designers, like Alexander et al. (1977), have argued, "[b]uilding set-backs from the street, originally invented to protect the public welfare by giving every building light and air, have actually helped greatly to destroy the street as social space." (p. 593). Likewise, citing the work of Raymond Unwin (1909), Andres Duany and other New Urbanists have strongly advocated for terminated vistas at the ends of street as a way of achieving enclosure in all directions (Duany & Plater-Zyberk, 1992; Duany, Plater-Zyberk, & Speck, 2000). Terminated vistas can be achieved both through the use of a "controlled curve" or the "careful placement of a public building" or other structure "worthy of honor" (Duany et al., 2000, p. 35) – features often employed in the more historical developments of Glasgow.

Figure 8, Table 9, and Table 10 show the frequency distribution and descriptive statistics for enclosure measures from all 693 sample street segments included in the dataset. Overall, enclosure scores were positively

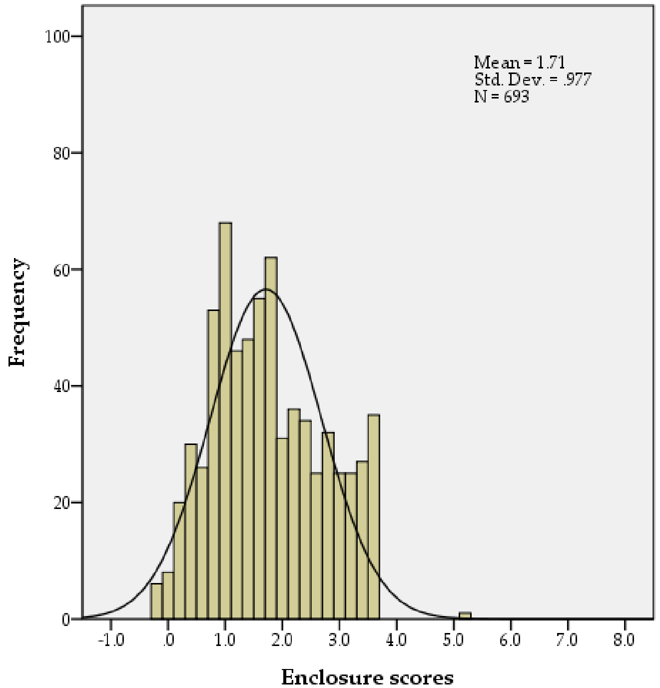


Figure 8 – Histogram of the enclosure scores

Table 9 – Descriptive statistics of the enclosure scores

	N	Min	Max	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
Enclosure Scores	693	-0.2	5.1	1.71 ± 0.98	0.95	0.31 ± 0.09	-0.73 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 10 – Shapiro-Wilk test of the enclosure scores

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.97	693	6.13E-11

skewed and non-normally distributed, with scores ranging from -0.16 to 5.10 and a mean ± standard of 1.77 ± 1.10.

3.4.1.4 Human scale

Human scale refers to the scale of physical elements in the built environment and how they relate to the size of pedestrians and the speed at which they travel. These elements may include building details, pavement texture, street trees, and street furniture. An advocate for human scale urban design, Camillo Sitte criticized the scale of modern city planning, arguing:

> *"The larger the city, the bigger and wider the plazas and streets become, and the higher and bulkier are all structures, until their dimensions, what with their numerous floors and interminable rows of windows, can hardly be organized any more in an artistically effective manner. Everything tends toward the immense, and the constant repetition of identical motifs is enough to dull our senses to such an extent that only the most powerful effects can still make any impression. As this cannot be altered, the city planner must, like the architect, invent a scale appropriate for the modern city of millions." (Sitte, 1889)*

Urban designers have often cited the ratio of building heights to street width as one of the most important elements in terms of human scale (Alexander et al., 1977, pp. 114-119; Blumenfeld, 1953; Hedman & Jaszewski, 1984, pp. 57-58). However, human scale can also relate to the rate at which pedestrians travel and how well they are able to perceive unique streetscape features.

Human scale was previously defined by consensus in Ewing and Handy (2009) and referred to in this study as: "a size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk" (p. 77). Streetscape features including building details, street trees, and street furniture can all contribute to human scale. Table 11 shows the best-fit model of the streetscape features used to compute scores for human scale in this study.

Table 11 – Best-fit human scale model

Variable	**Coefficient**	**p-value**
Constant	2.612	-
Long sight lines (0-3)	-0.744	0.001
Outdoor dining tables	-	-
Lights on buildings (not more than 4 meters high)	-	-
All street furniture and other street items	0.0364	0.001
Proportion window (street level)/street front	1.099	0.001
Building height	-3.040E-03	0.033
Small planters	0.0496	0.047
Urban designer	0.382	0.066

The number of long sight lines and the height of buildings on the same side of the street segment negatively influence the perception of human scale, while the presence of first floor windows, small planters and street furniture positively contribute to the perception of human scale. Similar visual assessment studies on architectural massing have shown that cross-sectional areas of buildings and the decoration, articulation, and partitioning of building facades were all important determinants of human scale perceptions (Stamps, 1998).

Figure 9, Table 12, and Table 13 show the frequency distribution and descriptive statistics for human scale measures from all 693 sample street segments included in the dataset. Overall, human scale scores were positively skewed and non-normally distributed, with scores ranging from 0.75 to 6.12 and a mean ± standard of 2.61 ± 1.05.

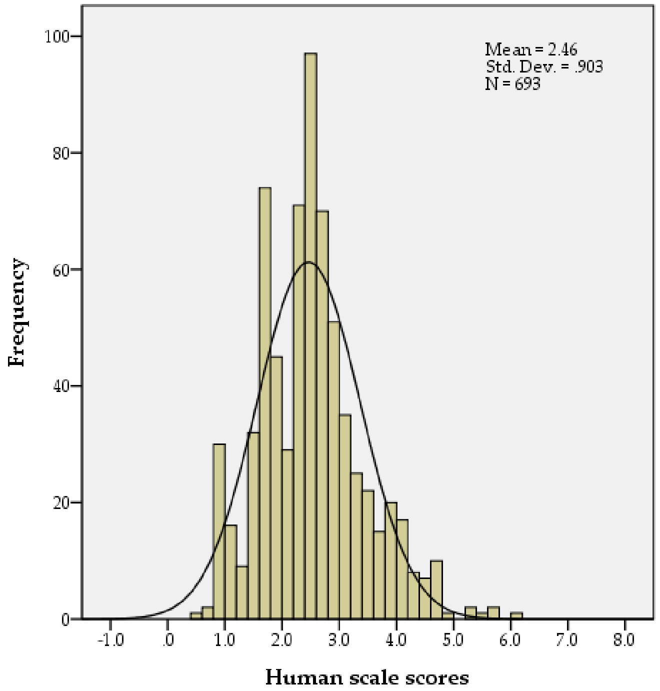


Figure 9 – Histogram of the human scale scores

Table 12 – Descriptive statistics of the human scale scores

	N	Min	Max	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
Human Scale Scores	693	0.5	6.1	2.46 ± 0.90	0.81	0.58 ± 0.09	0.66 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 13 – Shapiro-Wilk test of the human scale scores

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.97	693	4.24E-10

3.4.1.5 Transparency

Transparency is a quality that refers to the degree to which pedestrians can perceive what lies beyond the edge of a street, especially in terms of human activity. Allan Jacobs explained:

> *"The best streets have about them a quality of transparency at their edges, where the public realm of the street and the less public, often private realm of property and buildings meet. One can see or have a sense of what is behind whatever it is that defines the street; one senses an invitation to view or know, if only in the mind, what is behind the street wall." (1993, p. 285)*

It is typical for physical features like windows, doors, and narrow, mid-block openings to give a sense of transparency, while blank walls and garage doors reduce the quality of transparency (A. Jacobs, 1993, pp. 285-287). Street edges become more transparent when the internal activities become "externalized" (Llewelyn Davies Yeang, 2000), bringing them to the pavement. William Whyte explained, "the progression from street to interior is critical in this respect. Ideally, the transition should be such that it's hard to tell where one ends and the other begins" (Whyte, 1988, p. 130).

Transparency was previously defined by Ewing and Handy (2009) and referred to in this study as: "the degree to which people can see or perceive what lies beyond the edge of a street and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street" (p. 78). Streetscape features that relate directly to the quality of transparency include walls, windows, doors, fences, and landscaping. Table 14 shows the best-fit model of the streetscape features used to compute scores for transparency in this study.

Table 14 – Best-fit transparency model

Variable	Coefficient	p-value
Constant	1.709	-
Proportion of first floor with windows	1.219	0.002
Proportion of active uses on street front	0.533	0.004
Proportion of street wall	0.666	0.011

All physical features in this model have positive relationships to perceptions of transparency. Figure 10, Table 15, and Table 16 show the frequency distribution and descriptive statistics for transparency measures from all 693 sample street segments included in the dataset. Overall, transparency scores were positively skewed and non-normally distributed, with scores ranging from 1.71 to 4.13 and a mean ± standard deviation of 2.62 ± 0.77.

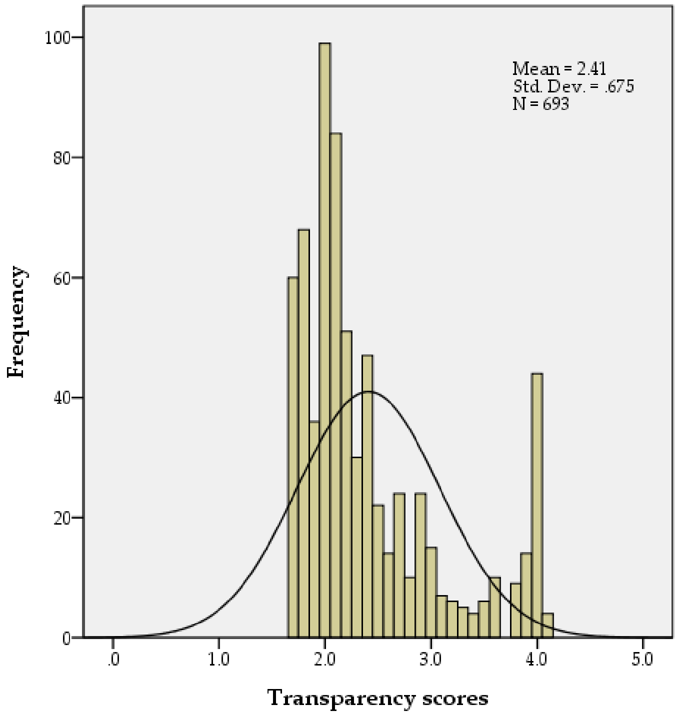


Figure 10 – Histogram of the transparency scores

Table 15 – Descriptive statistics of the transparency scores

	N	**Min**	**Max**	**Mean ± SD[a]**	**Variance**	**Skewness ± SE[a]**	**Kurtosis ± SE[a]**
Transparency Scores	693	1.7	4.1	2.41 ± 0.67	0.45	1.23 ± 0.09	0.45 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 16 – Shapiro-Wilk test of the transparency scores

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.83	693	1.38E-26

3.4.1.6 Complexity

Complexity is a quality that refers to the visual richness and variety of features in built environments (Rapoport & Kantor, 1967). As Allen Jacobs noted, "more buildings along a given length of street…fountains, benches, kiosks, paving, lights, signs, and canopies can all be important, at times crucially so" (1993, pp. 297-298). Gordon Cullen (1961) even went so far as to call elements, such as street signs, "the most characteristic, and, potentially, the most valuable, contribution of the twentieth century to urban scenery" (p. 151). Though, as Nasar (1987) found in the case of signs, people prefer only moderate levels of complexity, and Rapoport and Hawkes (1970) noted, "[e]vidence from psychological research has shown that both excessively simple and excessively chaotic visual fields are disliked" (p. 106). Jan Gehl even asserted that the perceived complexity of built environments could have a psychological effect, making the walking distances between two points seem shorter than they really were (Gehl, 1987). Nelessen (1994) stated as one of ten principles for urban design that "[v]ariations on basic patterns must be encouraged in order to prevent a dull sameness" (p. 224).

The quality of complexity has been measured in several previous studies and related to differences in building materials, shapes, dimensions, decorations, and setbacks (Elsheshtawy, 1997; T. Heath, Smith, & Lim, 2000; Stamps, 1999; Stamps, Nasar, & Hanyu, 2005).

Complexity was previously defined by Ewing and Handy (2009) and referred to in this study as simply: "the visual richness of a place" (p. 81). Complexity can relate specifically to the numbers and types of buildings, architectural diversity and ornamentation, landscape elements, street furniture, and signage. Table 17 shows the best-fit model of the streetscape features used to compute scores for complexity in this study.

Table 17 – Best-fit complexity model

Variable	Coefficient	p-value
Constant	1.453	-
Number of people	2.680E-02	0.001
Number of buildings	0.051	0.008
Dominant building colors	0.177	0.031
Accent building colors	0.108	0.043
Presence of outdoor dining	0.367	0.045
Pieces of public art	0.272	0.066

All physical features in this model have positive relationships to perceptions of complexity. Figure 11, Table 18, and Table 19 show the frequency distribution and descriptive statistics for complexity measures from all 693 sample street segments included in the dataset. Overall, complexity scores

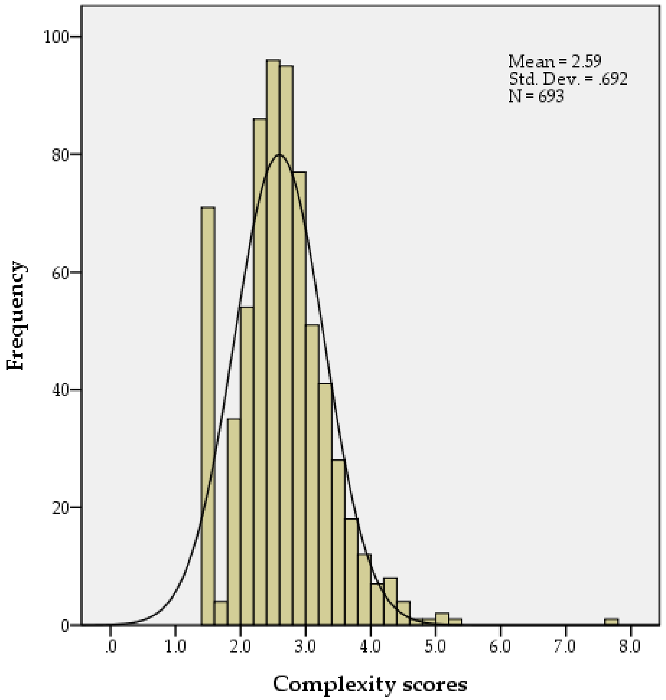


Figure 11 – Histogram of the complexity scores

Table 18 – Descriptives of the complexity scores

	N	Min	Max	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
Complexity Scores	693	1.50	7.60	2.59 ± 0.69	0.48	1.03 ± 0.09	4.20 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 19 – Shapiro-Wilk test of the complexity scores

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.94	693	8.01E-16

were positively skewed and non-normally distributed, with scores ranging from 1.45 to 7.67 and a mean ± standard deviation of 2.75 ± 0.82.

3.4.2 Control Variables (D Variables)

The influence of the built environment on travel behaviors and pedestrian activity has been one of the most researched topics within the field of urban planning and design. As Ewing and Cervero noted, "[t]he potential to moderate travel demand by changing the built environment is the most heavily researched subject in urban planning" (2010, p. 267). Within this body of research, potential influential factors, beyond those related to perceptual qualities of urban streetscapes have often been referred to as the "D variables." The term *D variables* was first coined by Cervero and Kockelman (1997) to describe the variables of density, diversity, and street network design. Additional D variables have since been established to include the potential influences like destination accessibility and distance to transit (Ewing & Cervero, 2001), and other variables like demand management (e.g., parking supply and cost) and demographics (Ewing & Cervero, 2010).

Control variables in this study were drawn from the characterization of the D variables previous described in Ewing and Cervero (2010) and frequently used in studies measuring the built environment in relation to travel studies and pedestrian activity. As Ameli et al. noted:

> *"The built environment has been measured or operationalized in terms [of] one or more of the six recognized D variables in over 200 studies (c.f. Badoe & Miller, 2000; Cao, Mokhtarian, & Handy, 2009; Cervero, 2003; Crane, 2000; Ewing & Cervero, 2001, 2010; Handy, 2005; G. W. Heath et al., 2006; Tracy E. McMillan, 2005; Tracy E McMillan, 2007; Pont, Ziviani, Wadley, Bennett, & Abbott, 2009; Brian E Saelens, Sallis, & Frank, 2003; Stead & Marshall, 2001). These studies explain trip frequencies, mode choice, trip distances and overall vehicle miles travelled. A large subset of studies explains pedestrian mode choice, or walking frequency, in terms of the D variables" (2015, p. 393).*

The D variables used as control variables in this study were those related to density, diversity, street network design, destination accessibility, distance to transit, and demographics, and were all computed using ArcGIS software (Esri Inc., 2015).

3.4.2.1 Density

Density is a D variable that is measured as a variable of interest per unit of gross or net area. Common variables of interest include population, dwelling units, employment, and building floor areas. In this study, two density measures were computed using GIS for the 400 meter buffer[29] around each sample street segment: (1) the average floor area ratio (FAR), computed as the total building floor area for all buildings located within the buffer divided by the total land area within the buffer, and (2) the average population density, computed as the population of all output areas whose centroids fell within the buffer divided by the gross buffer area, measured in one thousand residents per square km. Both of these measures have been used in several previous studies (e.g., Greenwald & Boarnet, 2001; Kockelman, 1997; Targa & Clifton, 2005) to account for the influence of density on walking behaviors as shown in Ewing and Cervero (2010). Other studies have also used measures of commercial floor area ratio (e.g., L. Frank, Bradley, Kavage, Chapman, & Lawton, 2008; L. Frank, Kavage, Greenwald, Chapman, & Bradley, 2009) and job density (e.g., Boarnet, Greenwald, & McMillan, 2008; Kockelman, 1997; Zhang, 2004). However, due to the lack of

[29] 400 m, or roughly a quarter-mile, is a typical buffer region, or pedestrian shed, considered comparable to a 5-minute walk.

accurate and available data on retail and job locations, these variables were not computed as additional control measures of density in this study.

Figure 12, Table 20, and Table 21 show the frequency distribution and descriptive statistics for buffer FAR measures from all 693 sample street segments included in the dataset. Overall, buffer FAR values were positively skewed and non-normally distributed, with values ranging from 0 to 6.30 and a mean ± standard deviation of 0.71 ± 0.60. Figure 13, Table 22, and Table 23 show the frequency distribution and descriptive statistics for population density measures from all 693 sample street segments included in the dataset. Overall, population density values were positively skewed and non-normally distributed, with values ranging from 0 to 16 thousand residents per km^2 and a mean ± standard deviation of 5.44 ± 2.98 thousand residents per km^2.

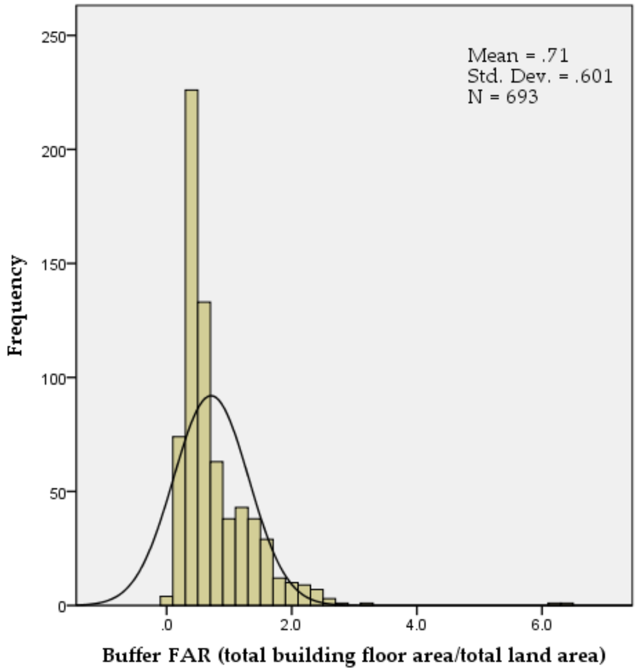


Figure 12 – Histogram of the buffer FAR values

Table 20 – Descriptive statistics of the buffer FAR values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.00	6.30	0.71 ± 0.60	0.36	3.12 ± 0.09	19.98 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 21 – Shapiro-Wilk test of the buffer FAR values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.75	693	4.79E-31

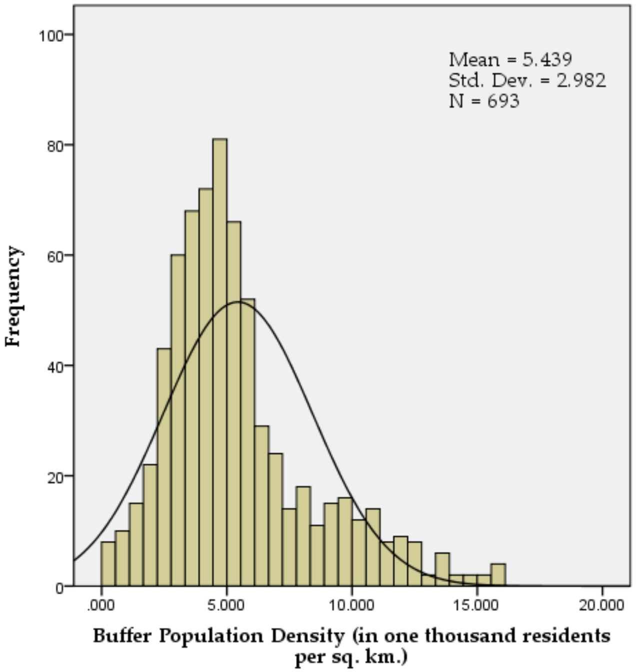


Figure 13 – Histogram of the population density values

Table 22 – Descriptive statistics of the population density values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.00	16.08	5.44 ± 2.98	8.89	1.11 ± 0.09	1.14 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 23 – Shapiro-Wilk test of the population density values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.92	693	5.84E-19

3.4.2.2 Diversity

Diversity is a D variable that relates to the number of different land uses per a given area and the extent to which the land uses are represented by land area, floor area, or employment. In this study, entropy measures of diversity were computed according to the following equation adapted from (L. Frank et al., 2008, p. 42):

$$Land\ use\ mix\ (entopy\ index) = -\sum P_i \times \frac{\ln P_i}{\ln n}$$

where, n = the number of different land use type classes in the 400-meter buffer region around the sample street segment (in this study n = 5, residential, leisure, education, office, and retail); and P_i = the proportion of total land area of the ith land-use category found in the buffer region. Values of land use entropy can range from 0 to 1, where lower values indicate areas with limited diversity of land uses and higher values indicating areas with more diversity of land uses.

Both of these measures have been used in several previous studies (e.g., L. Frank et al., 2008; L. Frank et al., 2009; Kockelman, 1997; Targa & Clifton, 2005; Zhang, 2004) to account for the influence of diversity on walking behaviors as shown in Ewing and Cervero (2010). Other studies have also used measures of job-housing balance (e.g., Bento, Cropper, Mobarak, & Vinha, 2003) or distance to a different types of stores (e.g., Cao, Handy, & Mokhtarian, 2006; Ewing et al., 2006; Handy, Cao, & Mokhtarian, 2006; Handy & Clifton, 2001) for measures of diversity. As geospatial data to compute these measures was not readily available, these additional measures of diversity were not incorporated into the controlled models.

Figure 14, Table 24, and Table 25 show the frequency distribution and descriptive statistics for buffer entropy measures from all 693 sample street segments included in the dataset. Overall, buffer entropy values were positively skewed and non-normally distributed, with values ranging from 0 to 0.76 and a mean ± standard deviation of 0.23 ± 0.15.

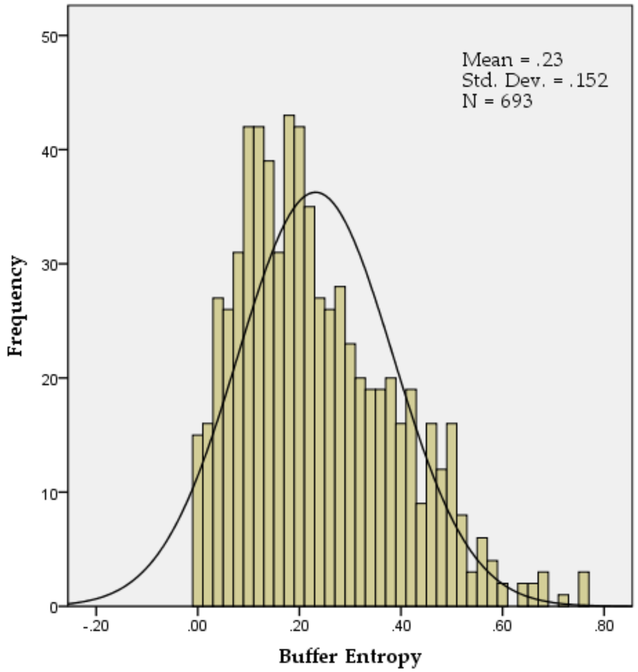


Figure 14 – Histogram of the buffer entropy values

Table 24 – Descriptive statistics of the buffer entropy values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.00	0.76	0.23 ± 0.15	0.02	0.73 ± 0.09	0.10 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 25 – Shapiro-Wilk test of the buffer entropy values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.95	693	4.22E-14

3.4.2.3 Street Network Design

Street network design is a D variable often accounted for using macroscale measures generated using GIS that have been shown as a potentially influential factors related to pedestrian activity (Boarnet, Joh, Siembab, Fulton, & Mai Thi Nguyen, 2011; L. Frank et al., 2008; Targa & Clifton, 2005). Street networks can vary in their design from dense, highly-connected grids to more sprawled out networks of long, curving streets in the suburbs. Measures of street network design can include block or street segment length, proportion of four-way intersections, and number of intersections per buffer area. The measures of street network design controlled for in this study were: (1) intersection density, computed as the number of intersections within the 400 m buffer around each sample street segment divided by the gross area of the buffer in square km, (2) proportion of four-way intersections within the buffer, and (3) sample street segment length in meters. Street network design can also be measured as a function of additional factors, including pavement coverage (i.e., share of street fronts with pavement) (Rodríguez & Joo, 2004), pavement width (Cervero & Kockelman, 1997), or other pedestrian environment features (Greenwald & Boarnet, 2001) that differentiate pedestrian-oriented environments from auto-oriented environments. In this study, all sample street segments were preselected as pedestrian-oriented, as previous noted above in Section 3.2. Therefore, these additional measures for design were not included as controls in this study.

Figure 15, Table 26, and Table 27 show the frequency distribution and descriptive statistics for intersection density measures from all 693 sample street segments included in the dataset. Overall, intersection density values were positively skewed and non-normally distributed, with values ranging from 24 to 292 intersections per km^2 and a mean ± standard deviation of 127.56 ± 47.06 intersections per km^2. Figure 16, Table 28, and Table 29 show the frequency distribution and descriptive statistics for proportion of four-way intersection measures from all 693 sample street segments included in the dataset. Overall, proportion of four-way intersection values were positively skewed and non-normally distributed, with values ranging from 0 to 0.39 and a mean ± standard deviation of 0.10 ± 0.07. Figure 17, Table 30, and Table 31 show the frequency distribution and descriptive statistics for sample street segment length measures from all 693 sample street segments included in the dataset. Overall, sample street segment length values were positively skewed and non-normally distributed, with values ranging from 28.80 to 228.0 meters and a mean ± standard deviation of 83.95 ± 31.36 meters. Though sample street segments were preselected to be a minimum of 50 m in

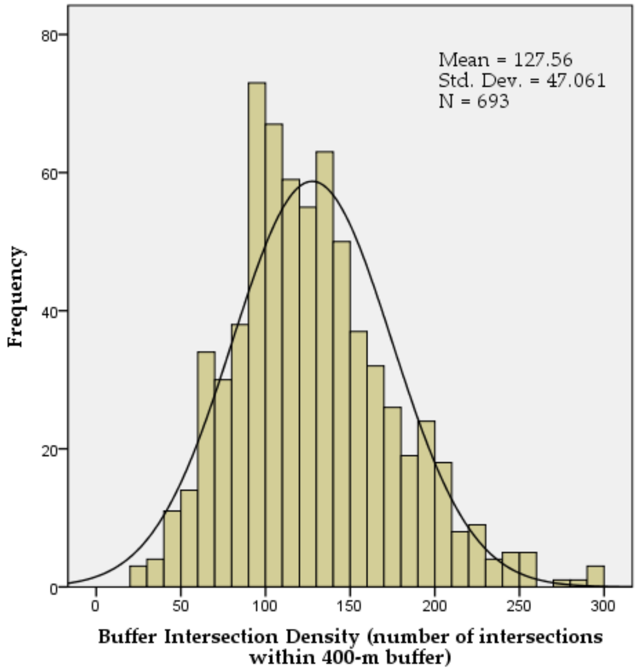


Figure 15 – Histogram of the buffer intersection density values

Table 26 – Descriptive statistics of the buffer intersection density values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	24	292	127.56 ± 47.06	2,214.78	0.60 ± 0.09	0.38 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 27 – Shapiro-Wilk test of the buffer intersection density values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.98	693	8.42E-09

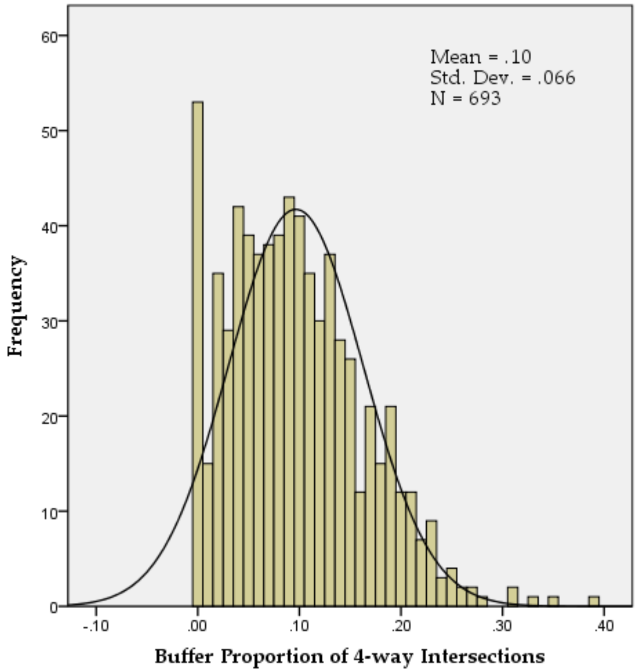


Figure 16 – Histogram of the buffer proportion of four-way intersections values

Table 28 – Descriptive statistics of the buffer proportion of four-way intersections values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.00	0.39	0.10 ± 0.07	4.39E-03	0.69 ± 0.09	0.45 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 29 – Shapiro-Wilk test of the buffer proportion of four-way intersections values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.96	693	4.97E-13

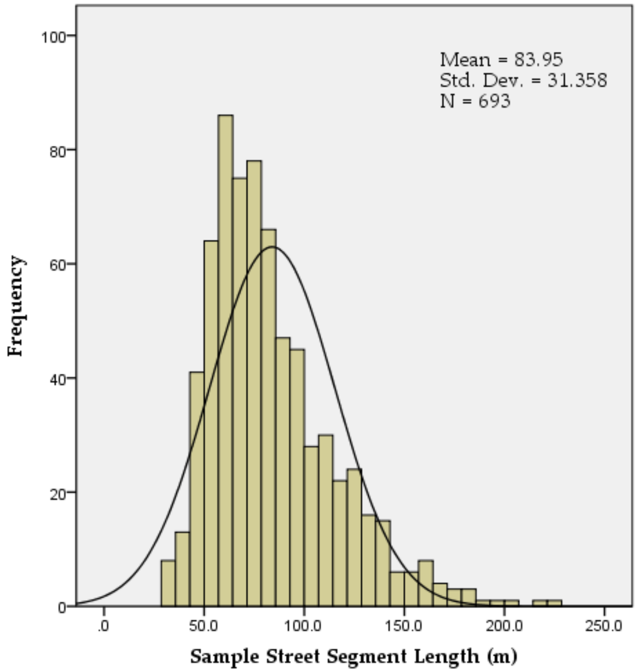


Figure 17 – Histogram of the sample street segment length values

Table 30 – Descriptive statistics of the sample street segment length values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	28.80	228.0	83.95 ± 31.36	983.33	1.15 ± 0.09	1.58 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 31 – Shapiro-Wilk test of the sample street segment length values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.92	693	3.61E-18

length, when centerline segments were snapped to the adjacent pavement (or sidewalk) in ArcGIS, the lengths were slightly adjusted and in some cases shortened.

3.4.2.4 Destination Accessibility

Destination accessibility is a D variable that measures the ease of access to local or regional destinations of interest (e.g., shops and jobs) (Handy, 1993). Regional accessibility can be measured as the distance to the central business district (Cervero, 2006) or the number of jobs (L. Frank et al., 2009) or other attractions reachable within a given travel time. Local accessibility is measured slightly differently and is defined by Handy (1993) as the distance from home to the closest "convenience establishment" (e.g., supermarkets, pharmacies, and dry cleaners).

Destination accessibility has more recently been measured in several studies using online rating tools such as Walk Score (Walk Score, 2016). Walk Score is an Internet-based platform that rates the walkability of a specific addresses based on its proximity to a number of different destinations. Walk Score ratings are made on a Likert scale from 0 to 100 based on the number of nearby stores and amenities (e.g., grocery stores, coffee shops, restaurants, bars, movie theatres, schools, parks, libraries, bookstores, fitness centers, drug stores, hardware stores, and clothing/music stores) within a one-mile radius of a selected address (Carr, Dunsiger, & Marcus, 2011). The higher the rating, the more accessible desirable destinations are to the selected address. Several studies have examined the use and validity of Walk Scores in measuring neighborhood walkability and access to amenities in the US (e.g., Carr et al., 2011; Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011). The studies by Carr et al. (2011) and Duncan et al. (2011) used GIS measures to validate Walk Score data, concluding that Walk Score values represented reliable measures of destination accessibility in multiple locations and across multiple geographic scales.

For this study, an address at the approximate midpoint of each sample street segment was retrieved from the address data layer in ArcGIS and recorded as part of the meta-data for each sample street segment. Later, this approximate midpoint address was entered into the Walk Score platform to obtain a score for each sample street segment.

Figure 18, Table 32, and Table 33 show the frequency distribution and descriptive statistics for destination accessibility measures from all 693 sample street segments included in the dataset. Overall, destination

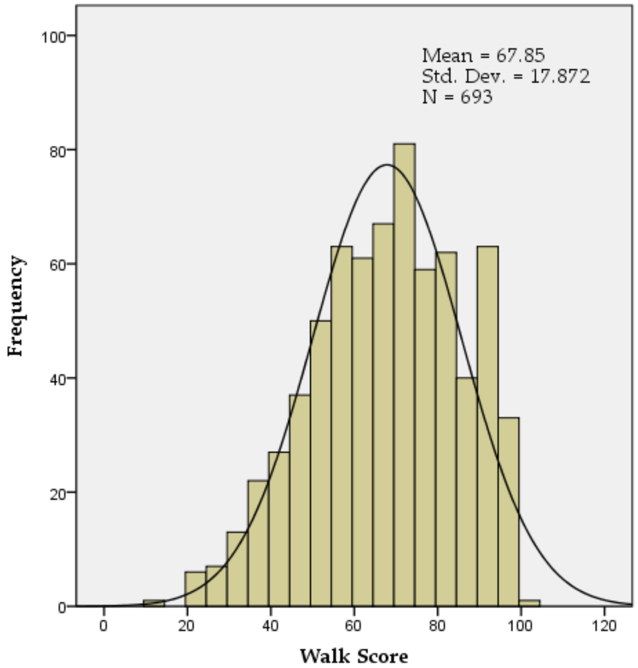


Figure 18 – Histogram of the destination accessibility values

Table 32 – Descriptive statistics of the destination accessibility values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	12	100	67.85 ± 17.87	319.40	-0.30 ± 0.09	-0.53 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 33 – Shapiro-Wilk test of the destination accessibility values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.98	693	4.73E-08

accessibility values were negatively skewed and non-normally distributed, with values ranging from 12 to 100 and a mean ± standard deviation of 67.85 ± 17.87.

3.4.2.5 Distance to Transit

Distance to transit is a D variable commonly measured as the average of the shortest routes from the midpoint of the sample street segment to the nearest rail station or bus stop (Bento et al., 2003; L. Frank et al., 2009). In this study, distance to transit was calculated using the ERSI ArcInfo Network Analyst toolbox. A network analysis was performed to find the shortest distance in meters from the mid-point of each sample street segment to the closest rail, bus, or subway station. The result was a distance-to-transit variable (in meters) related to each study segment.

Figure 19, Table 34, and Table 35 show the frequency distribution and descriptive statistics for distance-to-transit measures from all 693 sample street segments included in the dataset. Overall, distance-to-transit values were positively skewed and non-normally distributed, with values ranging from 0.10 to 1,464.50 meters and a mean ± standard deviation of 93.49 ± 117.09 meters.

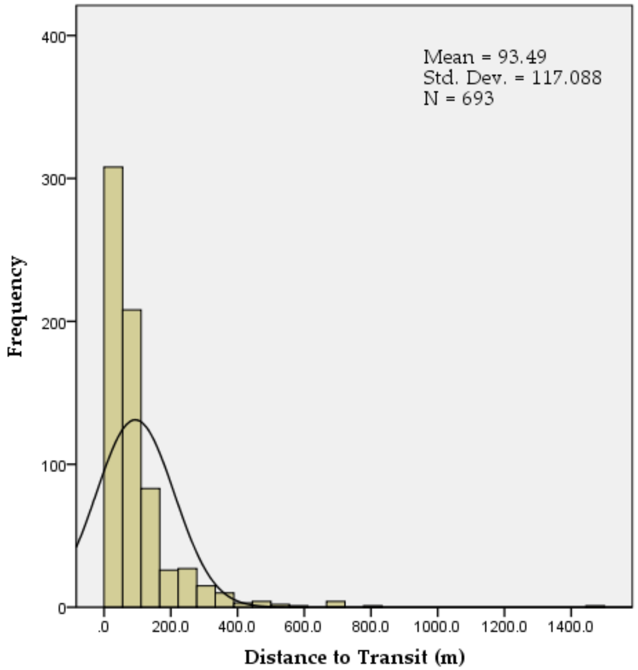


Figure 19 – Histogram of the distance-to-transit values

Table 34 – Descriptive statistics of the distance-to-transit values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.10	1,464.50	93.49 ± 117.09	13,709.56	4.26 ± 0.09	33.00 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 35 – Shapiro-Wilk test of the distance-to-transit values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.66	693	4.38E-35

3.4.2.6 Demographics

The only demographic D variable measured in this study was average household size for output areas whose centroids fell with the 400 m buffer around each sample street segment. Household size has been shown in previous studies (e.g., Ameli et al., 2015; Ewing & Clemente, 2013b) to be significantly ($p \leq 0.05$) related to average pedestrian counts. Additional demographic measures related to income (e.g., median household income and income per capita) are also sometimes computed; however, this data was not available at the resolution of the output area geography and thus these additional demographic measures were not incorporated into the controlled models.

Figure 20, Table 36, and Table 37 show the frequency distribution and descriptive statistics for average household size measures from all 693 sample street segments included in the dataset. Overall, average household size values were negatively skewed and non-normally distributed, with values ranging from 0 to 3.0 people per household and a mean ± standard deviation of 2.05 ± 0.31 people per household.

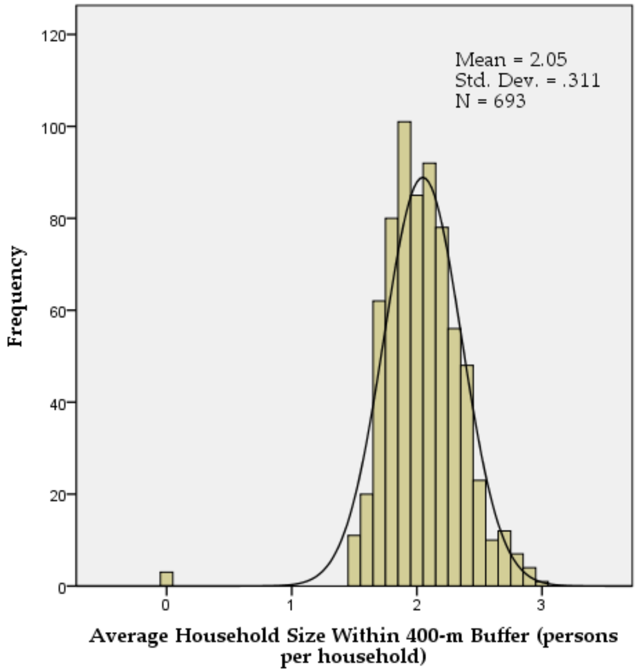


Figure 20 – Histogram of the average household size values

Table 36 – Descriptive statistics of the average household size values

N	Min.	Max.	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
693	0.00	3.00	2.05 ± 0.31	0.10	-0.80 ± 0.09	7.28 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE Standard Error

Table 37 – Shapiro-Wilk test of the average household size values

Shapiro-Wilk		
Statistic	*Degrees of freedom*	*p-value*
0.92	693	4.20E-19

3.4.3 Dependent Variable (Pedestrian Activity)

The dependent variable in this study was the average number of people encountered on four passes, also referred to as "walk-throughs," up and down one side[30] of the sample street segment. Measurements were made by walking the length of the sample street segment one time for each count and included every pedestrian encountered during the walk-through.

Due to the small sample size of these field counts and that counts were made in succession at different times and days of the week, there was a need to establish the reliability of the field counts in this study. Thus, additional counts were collected using two websites that provide street-level imagery, Google Street View and Bing Streetside, and then compared to the field counts for inter-rater reliability and scale reliability.

3.4.3.1 Note on the Use of Internet-Based, Street-Level Imagery

Google Street View (Google Inc., 2016) is a technology available online through Google Maps and Google Earth that allows users to see omni-directional street-level imagery shot continuously from the top of a moving car along public streets. Since its inception in 2007, Google Street View has

---

30 Where not defined by the topography of the street segments on the street network, the side of the sample street segment for observations was randomly selected.

been increasingly utilized in urban planning and design research as a reliable and cost-effective alternative to conducting in-person neighborhood and streetscape audits measuring walkability and bikeability (Badland et al., 2010; Clarke et al., 2010; Odgers et al., 2012; Rundle et al., 2011; Wilson et al., 2012).

Microsoft's Bing Streetside platform (Microsoft, 2016), available through Bing Maps, was also used to make additional counts for comparison with average field counts. Streetside imagery is similar to Google Street View, though often at slightly lower image resolutions. It is also worth noting that the majority of the Bing Streetside imagery around Glasgow was captured several years before (mostly in 2012) the imagery captured in Google Street View (mostly in 2015).

3.4.3.2 Reliability Testing

Two reliability tests were performed with respect to the field and virtual pedestrian counts. The first test was for inter-rater reliability for the counts made using the two Internet-based imagery resources. In Internet-based images, pedestrians can sometimes be partially hidden by other pedestrians, cars, trees, and other visual obstacles, and the images are also sometimes blurry. Therefore, it was assumed that there was some observer error associated with virtual counts made using Internet-based imagery. In order to test the effects of observer errors, an inter-rater reliability test was conducted by the author and 2 undergraduate research assistants. A random selection of 30 sample street segments[31] (with both high and low pedestrian counts) were selected from the dataset, and all 3 observers counted the total number of pedestrians on each of the 30 samples street segments using both Google Street View and Bing Streetside imagery.

In order to assess the inter-rater reliability of multiple individuals analyzing the same set of samples, intra-class correlation coefficients were computed using a two-way mixed ANOVA model with measures of consistency (see Table 38). The results in Table 38 represent estimates for the reliability of a single rating, as this study ultimately relied on the average pedestrian counts of a single observer (i.e., the author).

Table 38 – Intraclass correlation coefficients for a sample of thrity counts by 3 observers

Imagery Source	**Intraclass Correlation Coefficients (ICCs)**
Google	0.94
Bing	0.98

[31] This is a sample size analogous to that used in similar reliability studies (e.g., Clifton et al., 2007; T. J. Pikora et al., 2002).

Higher ICC values indicate greater inter-rater reliability, with estimates of 1 indicating perfect agreement, and estimates of 0 indicating random agreement (Hallgren, 2012). The intra-class correlation coefficients indicated almost perfect agreement according to the benchmarks for observer agreement suggested by Cicchetti (1994).

After establishing that pedestrian counts could be reliably counted across Internet-based sources, another test of reliability was conducted to compare all 693 field counts to counts from web-based street imagery. In order to test the internal consistency of this measures (i.e., how closely related the set of measures were as a group), Cronbach alpha (α) values were computed (see Table 39).

Table 39 – Cronbach's Alpha values for field counts versus Internet-based, street-level imagery counts

Statistic	Field counts vs. Google Street View Counts	Field counts vs. Bing Streetside Counts
Cronbach's alpha, α	0.91	0.88
Sample size, n	692	666

Cronbach α values are commonly used to assess scale reliability or how closely two indicators (or "scales") measure the same variable. While acceptable α values can range from 0.50 to 0.80 depending on the number of items in the scale, the stage and application of the research (Field, 2013, pp. 709-710). Kline (1999) noted that α values of 0.80 and greater are generally acceptable indicators of reliability. As the results from this second reliability test showed, comparisons between field counts and Internet-based, street-level imagery counts all indicated high degrees of reliability, and thus the average pedestrian counts collected in the field were considered appropriate for use in this study. Further statistical descriptions and analysis of the dependent average pedestrian counts variable is included in Chapter 4, as the distribution of this variable directly influenced the model selection used to generate results for this study.

3.5 Methodology

Primary data for the independent variables (streetscape qualities) and the dependent variable (pedestrian activity) was collected by the author on each of the 693 sample street segments over the course of two summers, 2014 and 2015, using helmet-mounted, GoPro action cameras. Video samples (see Figure 21) were collected and later analyzed following an innovative, validated video recording protocol developed by the author (see Appendix C for details) and field manual (see Appendix D for details) adapted from Ewing et al. (2005).

Figure 21 – Still image from video sample collected on Duke Street in Glasgow, UK

Auditing the video clips taken at each sample street segment location took on average approximately 15 minutes. Sample street segment were accessed mostly by bike or occasionally on foot (for sites located within walking distance from the University of Strathclyde)[32]. Sample street segments located in close proximity to one another were grouped together prior to sampling to allow for reduced travel time between segments during daily sampling. The following standardized sampling criteria were also set in place in order to achieve the most comparable pedestrian counts across all samples, representative of typical weekday flow:

[32] For the full scale project sampling, over 800 miles of biking and walk were logged by the author over the course of the two summers (2014 and 2015) traveling on bike between sample street segments and walking during video sampling.

- Samples may only be collected during the summer months at times when: (1) it is not raining at the time of sampling, (2) it has not been raining for at least an hour prior to sampling (allowing time for street furniture, etc. to dry), and (3) average daily temperatures were above yearly averages (approximately 13°C average high temperature).

- Samples may only be collected during the weekdays and during mid-day off-peak hours – i.e., 9:30AM until 4:00PM. Holidays or days of special events (e.g., Commonwealth Games) are also excluded.

While the majority of the methodologies for primary data collection and analysis are explained in Appendix C and Appendix D, the following subsections detail important notes regarding the reliability of these methods and related limitations.

3.5.1 Pilot Tests and Reliability Testing

Before using the video recording protocol (Appendix C) and adapted field manual (Appendix D) to collect and analyze data from each of the 693 sample street segments in the dataset, a pilot test was conducted to test the reliability of both of the instruments, using a subset of 30 randomly-selected sample street segments and 3 trained undergraduate research assistants. After an initial 1-day training, which included a classroom-based introduction to the video recording protocol and adapted field manual, the 3 undergraduate research assistants and the author independently conducted both in-person/on-street audits of the 30 samples street segments and also collected and analyzed video samples from each sample location according to the video recording protocol and field manual.

In order to assess the inter-rater reliability of multiple individuals analyzing the same set of 30 samples, intra-class correlation coefficients were computed using a two-way mixed ANOVA model with measures of consistency using the in-person, on-street audits (see Table 40). The results in Table 40 represent estimates for the reliability of a single rating for each computed streetscape quality, as this study ultimately relied on the streetscape quality scores of a single observer (i.e., the author).

Table 40 – Intraclass correlation coefficients for streetscape quality variables from 30 sample street segments by 4 observers

Streetscape Quality	**Intraclass Correlation Coefficients (ICCs)**
Imageability	0.92
Enclosure	0.92
Human scale	0.81
Transparency	0.91
Complexity	0.93

The intra-class correlation coefficients indicated almost perfect agreement according to the benchmarks for observer agreement suggested by Cicchetti (1994).

After establishing that streetscape qualities scores could be reliably scored by multiple trained observers, another test of reliability was conducted to compare scores collected using in-person, on-street audits and audits conducted via video samples. In order to test the internal consistency of these measures (i.e., how closely related the set of measures were as a group), Cronbach alpha (α) values were computed (see Table 41).

Table 41 – Cronbach's Alpha values for average streetscape quality measurements from 30 sample street segments taken from the field versus video clips by 4 observers

Streetscape Quality	**Cronbach's alpha, α**
Imageability	0.96
Enclosure	0.92
Human scale	0.96
Transparency	0.98
Complexity	0.96

As the results from this second reliability test showed, comparisons between field measures and video clip measures for each streetscape quality indicated high degrees of scale reliability. Overall, these results indicated that the video recording protocol and adapted field manual were reliable instruments for use in this study and were then used for data collection and analysis on the full-scale, city-wide study including all 693 samples street segments.

3.5.2 Limitations of the Methodology

One of the most significant limitations of this study is the limited counts of pedestrians conducted at each sample location. Others have suggested similar standardization of pedestrian accounts in order to account for this limitation. For example, Ameli et al. (2015) suggested counting the number of pedestrians over a 30-minute period at each sample street segment during hours of peak pedestrian activity (11:30-13:30 and 16:30-18:30 in the case of Salt Lake City) and non-inclement weather conditions (i.e., not in rain or periods of high winds). While longer standardized counts would be preferred, the scale of the case study area limited counts of pedestrians to the 4 walk-throughs, which were validated against two other randomized counts conducted using Internet-based, street-level imagery as described above.

3.6 Ethical considerations

Following the University of Strathclyde's guidance on ethics (University of Strathclyde, 2013a, 2013b), the required ethics, participant consent, and risk assessment forms[33] were completed and approved prior to field sampling and the use of undergraduate research students in pilot studies and reliability testing.

The main ethical issue related to this study involved the collection of potentially harmful data while video recording in public street environments. Harmful data could include, for example, incidents of crime witnessed in a public place.

All efforts were made during the collection, analysis, reporting, and storing of all data to avoid collecting and disclosing information that would be harmful to those potentially captured during on-street video recording. The data collected for this investigation was reported strictly in terms of mathematical values, without the need to disclose any personal information.

These ethical considerations were made in keeping with the American Psychological Association Ethics Code (effective 1 June 2010) Section 8.03 and the British Psychological Society Code of Ethics and Conduct (effective August 2009) Section 1.3.ix .

[33] Copies of these forms are provided in Appendix E for reference.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Introduction

This chapter details the results of this study examining the relationship between streetscape qualities and pedestrian activity in Glasgow, UK. The first section of this chapter covers a detailed description of the statistical distribution of the dependent variable (average pedestrian counts). All statistical analysis, unless noted otherwise, was conducted using the IBM statistical analysis software package *SPSS Statistics* (IBM Corp., 2015). The first section is followed by a discussion of how this distribution was then used to select the generalized linear regression model for statistically relating the control variables (D variables) and independent variables (streetscape qualities) to the average pedestrian counts. The third section presents an overview of the statistical modeling results using negative binomial generalized linear regression models. Statistical validation of these models is then explained before a more detailed discussion of the results, including notes on implications for the research and practice of urban design, and relevant limitations.

4.2 Statistical Description of the Dependent Variable

The method for statistically modeling the relationship between streetscape qualities and pedestrian activity was determined by the distribution of the dependent average pedestrian counts variable.

4.2.1 Frequencies

The distribution of the average pedestrian counts was initially evaluated using a histogram showing the frequency of average pedestrian counts (see Figure 22).

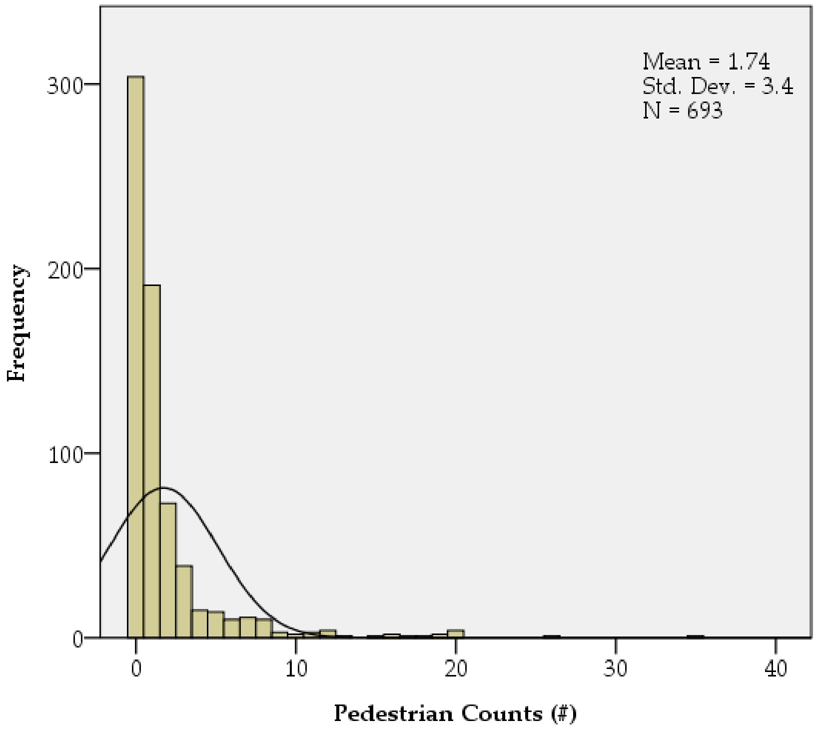


Figure 22 – Histogram of the dependent variable (average pedestrian counts)

The histogram shown in Figure 22 is a graphical representation of the probability distribution where each column (or "bin") contains a single value. For example, the first bin contains the value 0, indicating the frequency of 0 average pedestrian counts in the dataset, and so on. A normal curve (represented by the black line in Figure 22) was also generated based on the same mean and standard deviation as the data from the dataset.

Based on a visual inspection of the histogram, the distribution of the average pedestrian counts appeared to be unimodal, positively skewed, and non-normal. Further descriptive statistics and tests of normality were then conducted to confirm initial estimates related to the distribution of the average pedestrian counts variable.

4.2.2 Descriptive Statistics

The average pedestrian counts in the dataset, ranged from 0 to 35, with many of the sample street segments having low average pedestrian counts (304 sample street segments had an average pedestrian count of 0 or 1). The mean ± standard deviation of the average pedestrian counts was 1.74 ± 3.40, and the variance was 11.56. With the variance over 6 times larger than the mean, the distribution displayed signs of overdispersion. Full details of the descriptive statistics for the average pedestrian counts are shown in Table 42.

Table 42 – Descriptive statistics for the dependent variable (average pedestrian counts)

	N	Min	Max	Mean ± SD[a]	Variance	Skewness ± SE[a]	Kurtosis ± SE[a]
Average pedestrian counts	693	0	35	1.74 ± 3.40	11.56	4.28 ± 0.09	24.96 ± 0.19

[a]Abbreviations: SD, Standard deviation; SE, Standard error

4.2.2.1 Notes on Skewness and Kurtosis

The skewness value of the average pedestrian counts was 4.28, indicating a positively skewed distribution as shown in Figure 22. The skewness value measures the degree and direction of the distribution asymmetry. A skewness value of 0 indicates a symmetric distribution, while a positive skewness value indicates an asymmetrical distribution that is skewed to the right, and a negative skewness value indicates an asymmetrical distribution that is skewed to the left (see Figure 23).

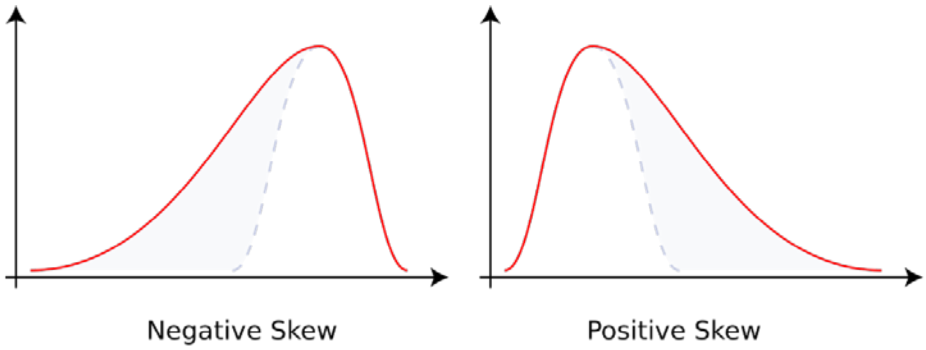


Figure 23 – Examples of negative and positive skew (Source: © Rodolfo Hermanss/Wikimedia/CC-BY-SA-3.0)

The kurtosis value of the average pedestrian counts was 24.96, indicating a higher propensity to produce outliers, or a "flatter" tail, as shown in the Figure 22 histogram. Kurtosis is a measure of the "heaviness," or "extremity," of the tails of a distribution – i.e., the "propensity to produce outliers" (Westfall, 2014, p. 191). Near-normal distributions have kurtosis values close to 0, while positive kurtosis values indicate the tails are "heavier" than normal distributions and negative kurtosis values indicate the tails are "lighter" than the normal distribution (see Figure 24).

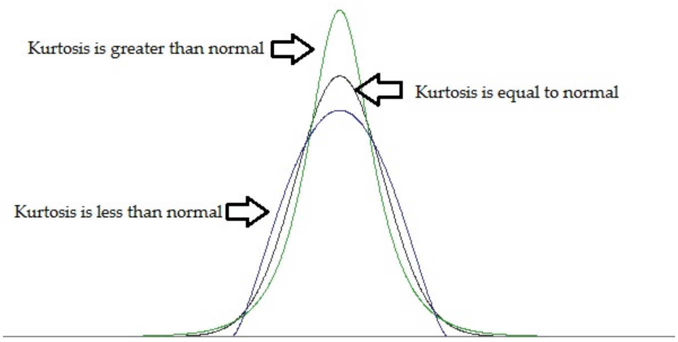


Figure 24 – Examples of kurtosis curves greater than (heavier), equal to, and less than (lighter) normal.

4.2.3 Test of Normality

While visual inspection of the histogram and descriptive statistics indicated that the distribution of average pedestrian counts was likely non-normal, a Shapiro-Wilk test (Shapiro & Wilk, 1965) of normality was also conducted (see Table 43) to test the discrepancy between the observed sample distribution and the corresponding normal curve, as advised by Ghasemi and Zahediasl (2012).

Table 43 – Shapiro-Wilk test of the dependent variable (average pedestrian counts)

	Shapiro-Wilk		
	Statistic	*Degrees of freedom*	*p-value*
Average Pedestrian Counts	0.52	693	1.65E-39

The Shapiro-Wilk test compares the observed sample distribution to an expected normal distribution using the Shapiro-Wilk (*W*) test statistic for normality, defined by the following equation (Shapiro & Wilk, 1965, p. 592):

$$W = \frac{\left(\sum_{i=1}^{n} a_i y_i\right)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2},$$

where y_i is the ith-order statistic; $\bar{y} = (y_1 + \ldots + y_n)/n$, which represents the sample mean; and a_i is a constant given by the following equation:

$$(a_1, \ldots, a_n) = \frac{m'V^{-1}}{\sqrt{(m'V^{-1}V^{-1}m)}},$$

where $m = (m_1,\ldots,m_n)'$ and $m_1,\ldots,m_n$ are the expected values of standard normal order statistics. V is the corresponding covariance matrix.

The null hypothesis (H_0) of the Shapiro-Wilk test is that the sample population is normally distributed. When $W = 1$, the sample variable data are perfectly normal (i.e., H_0 is not rejected). When W is significantly ($p \leq 0.05$) smaller than 1, the H_0 is rejected, and the distribution is considered non-normally distributed. Because the Shapiro-Wilk test is biased by the sample size (see Field, 2013, p. 184), the sample population, n, should be less than or equal to 2,000, as recommended by Royston (1982; 1992) and was the case in this study ($n = 693$). The results of the Shapiro-Wilk test ($W = 0.52$; $p = 1.65\text{E-}39$) indicated that the distribution of the dependent average pedestrian counts variable was non-normally distributed, thus the H_0 was rejected.

Additionally, a normal quantile-quantile (Q-Q) probability plot was used for further visual inspection of the distribution and validation of the Shapiro-Wilk test results. Q-Q plots are used to plot quantiles of data as opposed to accounting for each individual score as shown in the Figure 22 histogram.

Quantiles are values that split datasets into equal portions. The Q-Q plot of the average pedestrian counts variable (see Figure 25) showed that the observed quantiles (represented as individual points in Figure 25) departed from normality (represented by the straight, diagonal line Figure 25). Additionally, the pattern of the points wrapping about the normal line further validated earlier descriptive statistics regarding skewness and kurtosis. As noted by Field, when interpreting a Q-Q plot, "[k]urtosis is shown up [sic] by the dots sagging above or below the line, whereas skew is shown up [sic] by the dots snaking around the line in an 'S' shape" (2013, p. 185).

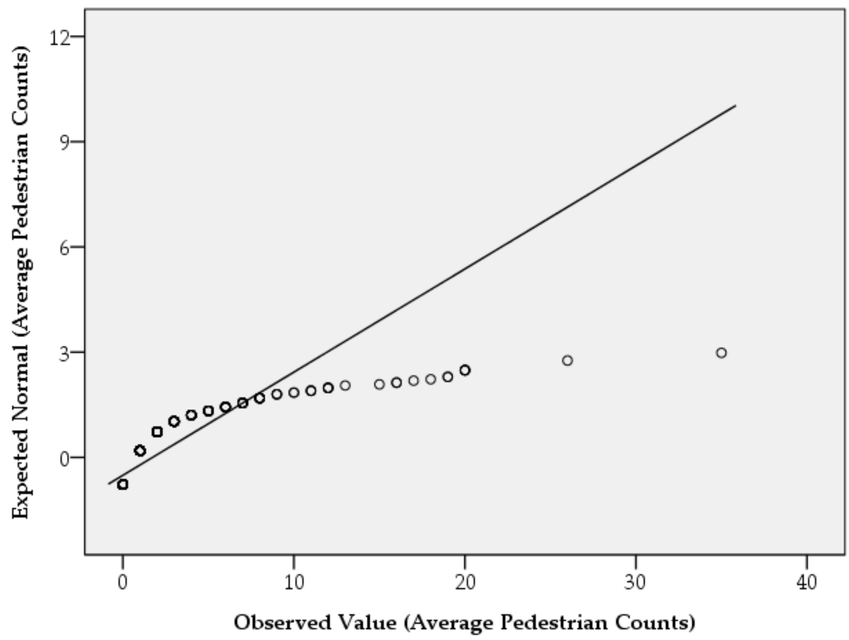


Figure 25 – Normal Q-Q plot of the dependent variable (average pedestrian counts)

4.2.4 Summary of the Statistical Description

According to the results presented above, it was determined that the distribution of the average pedestrian counts was positively skewed, positively kurtotic, and therefore non-normally distributed, thus indicating the need for a generalized linear regression model. The following section (Section 4.3) details the process for selecting the generalized linear regression model applied in this study.

4.3 Selection of the Generalized Linear Regression Model

Two types of generalized linear regression models are commonly used in regression analysis when the dependent variable is a count with non-negative integers and is non-normally distributed: (1) a Poisson regression or (2) a negative binomial regression (Vittinghoff, Shiboski, Glidden, & McCulloch, 2005).

Where these two models differ is in their assumptions regarding the relationship between the mean (μ) and variance (σ^2) of the dependent variable. A Poisson regression assumes that $\sigma^2 = \mu$, while a negative binomial regression assumes $\sigma^2 > \mu$.

As was the case in this study, the variance of the dependent average pedestrian counts variable (11.56) was over 6 times larger than the mean (1.74), indicating overdispersion. Long and Freese have noted, "the PRM [Poisson regression model] rarely fits, due to overdispersion. That is, the model under fits [sic] the amount of dispersion in the outcome" (2006, p. 372). Thus, a negative binomial regression was initially selected for statistical modeling in this study and later confirmed as the more appropriate generalized linear regression model using an estimated dispersion coefficient (see Section 4.5.1).

4.4 Results of the Negative Binomial Generalized Linear Regression Models

To compare the relationship between the control variables (D variables) and the independent variables (streetscape qualities) with the dependent variable (average pedestrian counts), two negative binomial regression models were generated (see Table 44). Model 1 was comprised only of the control variables, including measures of density, diversity, street network design, destination accessibility, distance to transit, and demographics. Model 2 was comprised of both the control variables and the independent variables, including imageability, enclosure, human scale, transparency, and complexity. Overall, many of the control variables had the expected relationships with the average pedestrian counts and were statistically significant ($p \leq 0.05$). Additionally, two of the five streetscape qualities, imageability and transparency, were also related to the average pedestrian counts at statistically significant levels ($p \leq 0.05$) – a novel finding for a city-wide study utilizing an adapted version of the Clemente et al. (2005) protocols. For a full discussion of the results, see Section 4.6.

4.5 Validation of the Negative Binomial Generalized Linear Regression Models

Before interpreting the results of the negative binomial regression models shown in Table 44, it was necessary to test the validity of the models. The following sections detail the tests that were used to: (1) confirm overdispersion and the use of the negative binomial regression analysis for statistical modeling, and (2) check for issues with multicollinearity and spatial autocorrelation amongst the variables.

4.5.1 Overdispersion Tests

To verify the overdispersion of the assumed negative binomial distribution, a dispersion coefficient (labeled "Estimated Dispersion Coefficient" in Table 44) was computed as part of the original output models using SPSS. A Poisson distribution is one in which this estimated dispersion coefficient is

Table 44 – Negative binomial generalized linear regression models

	Model 1						Model 2					
Parameter	**B**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**		**B**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**	
			Lower	*Upper*	*Wald Chi-Square*	*p-value*			*Lower*	*Upper*	*Wald Chi-Square*	*p-value*
(Intercept)	-2.41	0.56	-3.52	-1.31	18.26	1.90E-05	-3.33	0.52	-4.34	-2.32	41.63	1.10E-10
D_1.1	0.46	0.12	0.23	0.69	15.38	8.80E-05	0.31	0.09	0.13	0.49	11.15	8.39E-04
D_1.2	0.05	0.02	0.02	0.09	7.41	0.01	-4.50E-04	0.02	-0.04	0.04	6.23E-04	0.98
D_2	0.67	0.35	-0.01	1.36	3.69	0.05	0.37	0.32	-0.26	1	1.35	0.25
D_3.1	-3.27E-04	1.32E-03	-2.91E-03	2.26E-03	0.06	0.8	7.00E-05	1.16E-03	-2.20E-03	2.34E-03	3.63E-03	0.95
D_3.2	0.57	0.81	-1.02	2.15	0.49	0.49	0.18	0.72	-1.24	1.6	0.06	0.8
D_3.3	5.28E-03	1.59E-03	2.17E-03	0.01	11.06	8.81E-04	0.01	1.48E-03	0	0.01	13.88	1.94E-04
D_4	0.03	4.87E-03	0.02	0.04	38.28	6.13E-10	0.02	4.41E-03	0.01	0.03	18.25	1.90E-05
D_5	-0.01	7.10E-03	-0.01	-3.92E-03	55.94	7.46E-14	-0.01	6.65E-04	-0.01	-3.43E-03	50.65	1.10E-12
D_6	-0.21	0.2	-0.6	0.19	1.06	0.3	-0.23	0.18	-0.58	0.13	1.58	0.21
Q_1							0.18	0.08	0.03	0.33	5.69	0.02
Q_2							-0.08	0.06	-0.2	0.04	1.61	0.21
Q_3							1.95E-03	0.08	-0.15	0.15	6.53E-04	0.98
Q_4							0.73	0.1	0.54	0.92	56.89	4.60E-14
Q_5							-0.05	0.09	-0.23	0.12	0.37	0.55
Estimated Dispersion Coefficient	0.59	0.07	0.46	0.75			0.29	0.05	0.21	0.4		

Dependent Variable: Average pedestrian counts

Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size

Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

constrained to zero, while an estimate greater than zero confirms overdispersion (UCLA: Statistical Consulting Group, 2016). As the estimates were all greater than 0, and the 95% confidence intervals also did not include a 0, the results of the estimated dispersion coefficient confirmed that the negative binomial regression was more appropriate than the Poisson regression for statistical modeling in this study.

4.5.2 Multicollinearity Tests

Multicollinearity between the variables in the models was a concern as some of the variables are comprised of similar measures (see full list of streetscape features from best-fit models in Section 3.41). Multicollinearity exists when there is a correlation between two or more predictor variables in a model. If collinearity exists between variables in the model, it is difficult to obtain unique estimates of the regression coefficients – i.e., the *B* values from the models become interchangeable. As the degree of multicollinearity increases, the *B* values can become unreliable, and their associated standard errors may become inflated, meaning that the *B* values are more variable across the samples (Field, 2013, pp. 324-325).

As an initial check for multicollinearity, a correlation matrix of the predictor variables was generated to determine the correlation values between the variables used in the models (see Table 45). Strong correlation values are indicated by $|r|$ values > 0.80. None of the correlation coefficients showed signs of strong correlation among the predictor variables used in this study, as all $|r|$ values were < $|0.40|$, with the exception of the *r* value ($r = -0.61$) between Q_1 (imageability) and Q_5 (complexity).

Additionally, Pearson correlations were also computed for each pairing of variables included in the models (see Table 46). These correlations measure both the strength and direction of the linear relationship between two variables and can range from -1 to +1. A value of -1 indicates a perfect negative correlation, a value of +1 indicating a perfect positive correlation, and 0 value indicates no correlation at all.

Tolerance and variance inflation (VIF) values were also computed for each of the variables used in the models (see Table 47). Tolerance is an indication of the percentage of variance in the variable that cannot be account for by the other variables. VIF is a ratio of 1 divided by the tolerance value and is a measure of the linear relationship between predictor variables. Common rules of thumb state that values of tolerance that are less than 0.10 and VIF values greater than 5.0 may indicate a problem with multicollinearity (Hair, Black, Babin, Anderson, & Tatham, 2006; Marquardt, 1970; Menard, 1995).

Table 45 – Correlation matrix for predictor variables used in the negative binomial generalized linear regression models

	Coefficient Correlations, r													
	Q_5	**D_5**	**D_3.3**	**D_3.2**	**D_2**	**D_6**	**D_3.1**	**Q_2**	**D_1.2**	**Q_4**	**D_4**	**Q_3**	**D_1.1**	**Q_1**
Q_5	-	0.05	-0.07	-0.05	-0.03	0.06	-0.09	0.18	-0.08	-0.11	0.08	-0.26	0.11	-0.61
D_5	0.05	-	0.00	0.01	0.12	0.18	-0.02	-0.10	0.07	0.08	0.10	-0.03	0.00	-0.09
D_3.3	-0.07	0.00	-	0.02	0.00	-0.09	0.03	-0.07	0.11	0.13	-0.05	0.06	0.01	-0.18
D_3.2	-0.05	0.01	0.02	-	0.02	-0.09	0.05	0.01	0.01	0.02	-0.17	-0.01	-0.13	0.03
D_2	-0.03	0.12	0.00	0.02	-	0.05	-0.01	0.02	0.27	-0.02	-0.20	-0.04	-0.16	0.00
D_6	0.06	0.18	-0.09	-0.09	0.05	-	-0.18	0.09	-0.03	0.08	0.23	-0.12	0.20	-0.07
D_3.1	-0.09	-0.02	0.03	0.05	-0.01	-0.18	-	0.03	-0.08	0.04	-0.25	-0.05	-0.34	0.08
Q_2	0.18	-0.10	-0.07	0.01	0.02	0.09	0.03	-	-0.14	-0.18	-0.05	-0.39	-0.05	-0.07
D_1.2	-0.08	0.07	0.11	0.01	0.27	-0.03	-0.08	-0.14	-	0.04	-0.28	0.04	-0.29	-0.17
Q_4	-0.11	0.08	0.13	0.02	-0.02	0.08	0.04	-0.18	0.04	-	-0.14	-0.37	-0.14	-0.12
D_4	0.08	0.10	-0.05	-0.17	-0.20	0.23	-0.25	-0.05	-0.28	-0.14	-	0.03	-0.18	-0.05
Q_3	-0.26	-0.03	0.06	-0.01	-0.04	-0.12	-0.05	-0.39	0.04	-0.37	0.03	-	0.00	-0.05
D_1.1	0.11	0.00	0.01	-0.13	-0.16	0.20	-0.34	-0.05	-0.29	-0.14	-0.18	0.00	-	-0.07
Q_1	-0.61	-0.09	-0.18	0.03	0.00	-0.07	0.08	-0.07	-0.17	-0.12	-0.05	-0.05	-0.07	-

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size
Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

Table 46 – Pearson correlation matrix for predictor variables used in the negative binomial generalized linear regression models

	Pearson Correlations (p-value)							
	PC	Q_1	Q_2	Q_3	Q_4	Q_5	D_1.1	D_1.2
PC	-	0.48 (8.84E-41)	0.36 (1.06E-22)	0.50 (4.47E-45)	0.60 (7.74E-70)	0.40 (1.56E-28)	0.56 (1.46E-59)	0.41 (3.78E-30)
Q_1.1	0.48 (8.84E-41)	-	0.46 (1.78E-37)	0.60 (2.87E-69)	0.59 (8.05E-67)	0.78 (2.54E-143)	0.42 (1.30E-31)	0.52 (1.29E-49)
Q_2	0.36 (1.06E-22)	0.46 (1.78E-37)	-	0.64 (1.71E-81)	0.61 (2.61E-71)	0.36 (5.51E-22)	0.47 (4.67E-40)	0.48 (5.32E-42)
Q_3	0.50 (4.47E-45)	0.60 (2.87E-69)	0.64 (1.71E-81)	-	0.72 (1.22E-109)	0.61 (1.45E-70)	0.43 (8.69E-32)	0.44 (9.52E-34)
Q_4	0.60 (7.74E-70)	0.59 (8.05E-67)	0.61 (2.61E-71)	0.72 (1.22E-109)	-	0.55 (5.28E-57)	0.55 (6.59E-56)	0.50 (5.88E-46)
Q_5.1	0.40 (1.56E-28)	0.78 (2.54E-143)	0.36 (5.51E-22)	0.61 (1.45E-70)	0.55 (5.28E-57)	-	0.32 (1.10E-17)	0.43 (5.36E-32)
D_1.1	0.56 (1.46E-59)	0.42 (1.30E-31)	0.47 (4.67E-40)	0.43 (8.69E-32)	0.55 (6.59E-56)	0.32 (1.10E-17)	-	0.65 (8.07E-85)
D_1.2	0.41 (3.78E-30)	0.52 (1.29E-49)	0.48 (5.32E-42)	0.44 (9.51E-34)	0.50 (5.88E-46)	0.43 (5.36E-32)	0.65 (8.07E-85)	-
D_2	0.20 (2.30E-07)	0.11 (2.63E-03)	0.12 (1.36E-03)	0.16 (3.46E-05)	0.20 (5.78E-08)	0.11 (3.80E-03)	0.28 (9.44E-14)	0.04 (0.35)
D_3.1	0.36 (2.79E-22)	0.31 (2.26E-16)	0.32 (1.62E-17)	0.33 (2.60E-19)	0.38 (1.27E-24)	0.28 (9.21E-14)	0.61 (8.10E-73)	0.50 (2.32E-45)
D_3.2	0.17 (5.38E-06)	0.15 (8.18E-05)	0.15 (1.20E-04)	0.16 (3.47E-05)	0.18 (1.15E-06)	0.14 (1.82E-04)	0.30 (8.32E-15)	0.22 (3.65E-09)
D_3.3	-5.20E-03 (0.89)	0.16 (3.77E-05)	-0.02 (0.69)	-0.02 (0.61)	-0.08 (0.03)	0.13 (9.29E-04)	-0.09 (0.02)	-0.08 (0.04)
D_4.1	0.44 (8.92E-35)	0.41 (1.29E-29)	0.46 (1.51E-37)	0.41 (1.14E-28)	0.54 (1.22E-53)	0.31 (2.39E-17)	0.70 (1.55E-102)	0.63 (2.04E-78)
D_5	-0.15 (6.61E-05)	1.57E-03 (0.97)	0.05 (0.23)	-0.01 (0.74)	-0.08 (0.05)	-0.04 (0.33)	-0.08 (0.03)	-0.09 (0.01)
D_6	-0.21 (4.39E-08)	-0.13 (3.92E-04)	-0.26 (2.18E-12)	-0.14 (2.85E-04)	-0.27 (2.07E-13)	-0.11 (5.85E-03)	-0.38 (4.03E-25)	-0.25 (4.41E-11)

Dependent Variable: PC_Average pedestrian counts

Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size

Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

Pearson Correlations (p-value)							
	D_2	D_3.1	D_3.2	D_3.3	D_4.1	D_5	D_6
PC	0.20 (2.30E-07)	0.36 (2.79E-22)	0.17 (5.38E-06)	5.20E-03 (0.89)	0.44 (8.92E-35)	-0.15 (6.61E-05)	-0.21 (4.39E-08)
Q_1.1	0.11 (2.63E-03)	0.31 (2.26E-16)	0.15 (8.18E-05)	0.16 (3.77E-05)	0.41 (1.29E-29)	1.57E-03 (0.97)	-0.13 (3.92E-04)
Q_2	0.12 (1.36E-03)	0.32 (1.62E-17)	0.146 (1.20E-04)	-0.02 (0.69)	0.46 (1.50E-37)	0.05 (0.23)	-0.26 (2.18E-12)
Q_3	0.16 (3.46E-05)	0.33 (2.60E-19)	0.16 (3.47E-05)	-0.02 (0.61)	0.41 (1.14E-28)	-0.01 (0.74)	-0.14 (2.85E-04)
Q_4	0.20 (5.78E-08)	0.38 (1.27E-24)	0.18 (1.15E-06)	-0.08 (0.03)	0.54 (1.22E-53)	-0.08 (0.05)	-0.27 (2.07E-13)
Q_5.1	0.11 (3.80E-03)	0.28 (9.21E-14)	0.14 (1.82E-04)	0.13 (9.29E-04)	0.31 (2.39E-17)	-0.04 (0.33)	-0.11 (0.01)
D_1.1	0.28 (9.44E-14)	0.61 (8.80E-73)	0.29 (8.32E-15)	-0.09 (0.02)	0.70 (1.55E-102)	-0.08 (0.03)	-0.38 (4.03E-25)
D_1.2	0.04 (0.35)	0.50 (2.32E-45)	0.22 (3.65E-09)	-0.08 (0.04)	0.63 (2.04E-78)	-0.09 (0.01)	-0.25 (4.41E-11)
D_2	-	0.19 (3.57E-07)	0.09 (0.03)	-0.01 (0.70)	0.31 (2.38E-16)	-0.14 (3.84E-04)	-0.17 (1.17E-05)
D_3.1	0.19 (3.57E-07)	-	0.19 (5.82E-07)	-0.06 (0.10)	0.57 (3.52E-61)	-0.09 (0.02)	-0.14 (2.32E-04)
D_3.2	0.09 (0.03)	0.19 (5.82E-07)	-	-0.03 (0.43)	0.31 (2.03E-16)	-0.06 (0.10)	-0.06 (0.13)
D_3.3	-0.01 (0.70)	-0.06 (0.10)	-0.03 (0.43)	-	-0.06 (0.11)	0.02 (0.58)	0.12 (1.17E-03)
D_4.1	0.31 (2.38E-16)	0.57 (3.52E-61)	0.31 (2.03E-16)	-0.06 (0.11)	-	-0.14 (3.45E-04)	-0.39 (3.18E-26)
D_5	-0.14 (3.84E-04)	-0.09 (0.02)	-0.06 (0.10)	0.02 (0.58)	-0.14 (3.45E-04)	-	-0.11 (0.01)
D_6	-0.17 (1.17E-05)	-0.14 (2.32E-04)	-0.06 (0.13)	0.12 (1.17E-03)	-0.39 (3.18E-26)	-0.11 (5.12E-03)	-

Dependent Variable: PC_Average pedestrian counts
Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size
Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

Table 47 – Multicollinearity statistics for predictor variables used in the negative binomial generalized linear regression models

Variable	Collinearity Statistics		Variable	Collinearity Statistics	
	Tolerance	*VIF*		*Tolerance*	*VIF*
D_1.1	0.34	2.93	**Q_1**	0.31	3.25
D_1.2	0.41	2.47	**Q_2**	0.48	2.10
D_2	0.81	1.23	**Q_3**	0.35	2.85
D_3.1	0.55	1.81	**Q_4**	0.35	2.83
D_3.2	0.88	1.13	**Q_5**	0.34	2.97
D_3.3	0.90	1.12			
D_4	0.36	2.75			
D_5	0.91	1.10			
D_6	0.74	1.35			

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size
Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

The lowest tolerance and highest VIF values were found in the imageability variable at 0.31 and 3.25 respectively. Together with the results from the correlation matrix, these results indicated that multicollinearity was not an issue, and there was little reason for concerns over redundancy in the variables.

4.5.3 Spatial Autocorrelation Tests

Negative binomial regressions also assume that the measured values of the dependent variable are independent of one another. Since observations of average pedestrian counts may be related by their spatial proximity (see

Figure 26), it was necessary to test for spatial autocorrelation in the residuals of the negative binomial regression models.

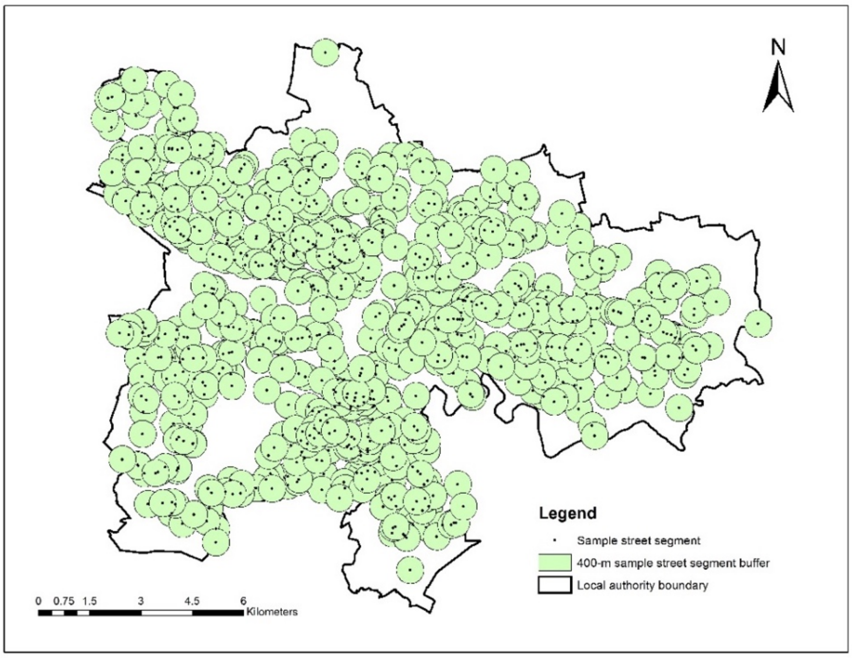


Figure 26 – Spatial proximity of sample street segments and their 400-m walkshed buffers within the case study area

Spatial autocorrelation may be positive or negative. In this study, positive spatial autocorrelation would have indicated that similar values of pedestrian counts occurred near one another. Negative spatial autocorrelation would have indicated that dissimilar values occurred near one another. If spatial autocorrelation does not exist, then the results of the negative binomial regression models are valid.

4.5.3.1 The Moran's I Test

A Moran's I test (Moran, 1950) was used for testing spatial autocorrelation. While the Moran's I test generates similar results as the Geary's C statistic (Geary, 1954), another commonly used test for spatial auto correlation, the Moran's I test is often preferred, as it has been shown by Cliff and Ord (1975, 1981) to be more consistently powerful.

The Moran's I test statistic, *I*, is based on sample locations and sample values. Given a set of samples and an associated attribute (e.g., average pedestrian counts), it evaluates whether the pattern expressed in the dataset is clustered, dispersed, or random based on cross products of the deviations from the mean. *I* is calculated according to the following equation (Esri Inc., 2015):

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

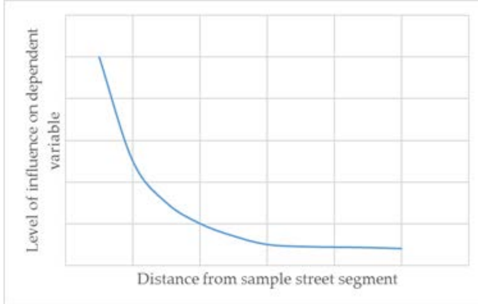
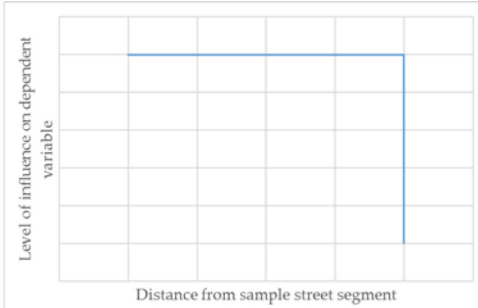
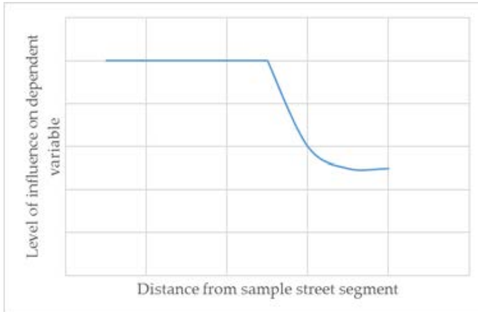
where n is the number of observations of variable x, i and j are locations, $\bar{x}$ is the mean of the x variable, $w_{i,j}$ are elements of a weight matrix, and S_0 is the sum of the elements of a weight matrix: $S_0 = \sum_i \sum_j w_{i,j}$.

Moran's I test statistics can vary between -1 to 1. *I* values higher than -1/(n - 1) indicate positive spatial autocorrelation, while *I* values lower than -1/(n - 1) indicate negative spatial autocorrelation.

4.5.3.2 Conceptualizations of the Spatial Relationship

Before testing for spatial autocorrelation using the Moran's I test, a realistic conceptualization of the spatial relationship was determined. In order to reflect the inherent spatial relationship between data points, several types of conceptualizations can be used (see Table 48 for common examples). For this study two conceptualizations of spatial relationships were used based on the assumption that average pedestrian counts on sample street segments located within a walkable distance of one another (i.e., within a 400 m walkshed) were more likely to influence one another. The two conceptualizations of spatial relationships used to compute the Moran's I test statistics were: (1) the zone of indifference conceptualization and (2) the distance band conceptualization, using a spatial weights matrix. The inverse distances conceptualization was ruled out given the scale of the study area and the fact that it forces all data points to be a neighbor to all other features in the dataset.

Table 48 – Conceptualizations of spatial relationships for Moran's I test

Conceptualization of Spatial Relationships	**Description**	**Figures**
Inverse distance or Inverse distance squared	This conceptualization is based on an impedance or distance decay model of spatial relationships. It assumes that all features influence all other features, but that the farther away a feature is, the smaller its influence.	
Distance band	This conceptualization is used when imposing a buffer of influence on the spatial interactions of the data. Each feature is analyzed within the context of those neighboring features located within a specified buffer distance. Data points within the specified buffer distance are weighted equally, while features outside the specified distance are assumed to have no influence (i.e., their weight is zero).	
Zone of indifference	This conceptualization combines the inverse distance and fixed distance band models. Features within the distance band or threshold distance are included in analyses, while the level of influence for those located outside the threshold distance decays over distance.	

4.5.3.3 Results of the Moran's I Test Using the Zone of Indifference Conceptualization

Using the zone of indifference conceptualization, a Moran's I test was conducted using Environmental Systems Research Institute (Esri) ArcGIS (Esri Inc., 2015) and a standard 400 m distance band (see Figure 27). The results indicated that spatial autocorrelation was nonsignificant ($p = 0.54$) using the zone of indifference conceptualization. However, one of the assumptions of the zone of indifference conceptualization is that all features influence all other features in the dataset, but that the farther away a feature is from the fixed 400 m distance band, the smaller its influence. In reality, given the spatial scale of the study area, it was unlikely that spatial outliers beyond the 400 m threshold distance were having much of an effect, if any. Therefore, another Moran's I test was conducted using the fixed distance band conceptualization and a spatial weights matrix to account for spatial outliers.

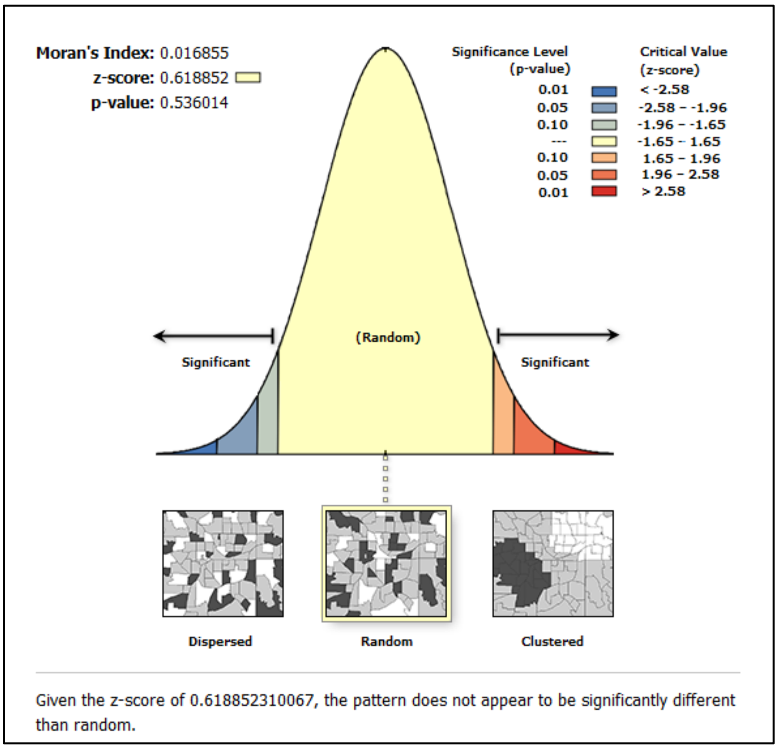


Figure 27 – ArcGIS spatial autocorrelation report for zone of indifference conceptualization

4.5.3.4 Results of the Moran's I Test Using the Distance Band Conceptualization with a Spatial Weights Matrix

In the second test, to determine an appropriate distance band for all but the spatial outliers, a spatial weights matrix was created using the Spatial Statistics Tools in ArcGIS, the same threshold distance of 400 m, and a minimum number of 2 neighbors. This meant that the Moran's I test applied a fixed 400 m distance band to all data points in the dataset except those that did not have at least two neighbors (a condition of a valid Moran's I test) within the threshold distance. For those spatial outliers, the distance band was expanded just enough to ensure that only those spatial outliers had at least two neighbors. Using that spatial weights matrix and the distance band conceptualization, the second Moran's I test (see Figure 28) also resulted in statistically nonsignificant spatial autocorrelation in the residuals of the model (p = 0.11).

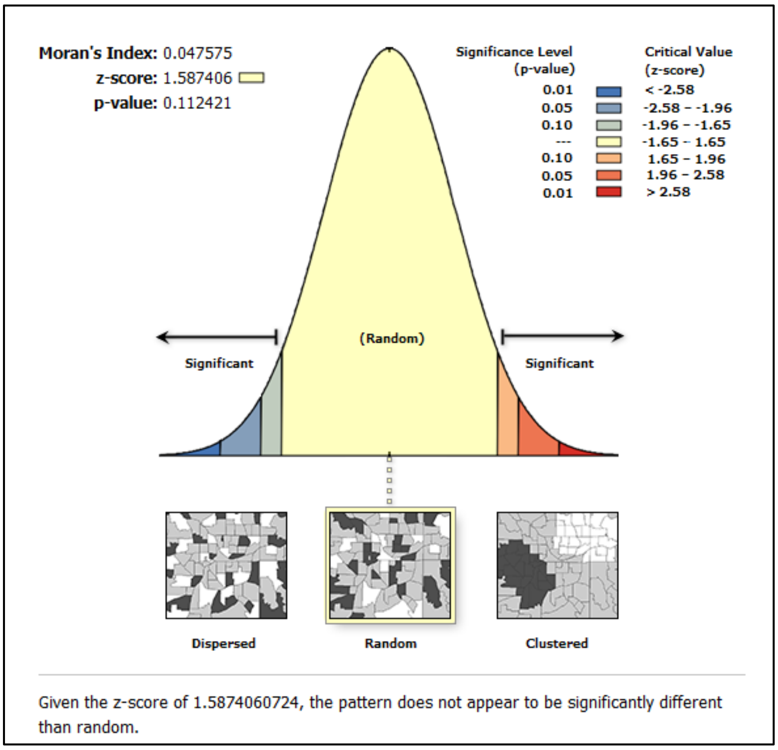


Figure 28 – ArcGIS spatial autocorrelation report for distance band conceptualization using spatial weights matrix

Results from these two tests confirmed that spatial autocorrelation was not present. Therefore, the results from the negative binomial regression models were valid.

4.6 Discussion of the Results from the Negative Binomial Generalized Linear Regression Models

The purpose of this study was to test the validation of using streetscape qualities as variables in modeling the relationship between measures of the built environment related to walkability and pedestrian activity. The following sections provide a more detailed discussion of the results presented in Section 4.4, with notes on relevant limitations and the implications for future urban design research and practice.

4.6.1 Goodness of Fit Comparison

Overall, both models had significant ($p \leq 0.05$) likelihood ratio chi-squared (X^2) statistics, indicating a good fit relative to the intercept-only, or "null," model without any predictor variables (see Table 49).

Table 49 – Likelihood ratio X^2 test results for Model 1 and Model 2

Model 1			Model 2		
Likelihood Ratio X^2	**df**	**p-value**	**Likelihood Ratio X^2**	**df**	**p-value.**
396.28	9	0.001<	528.15	14	0.001<

Moreover, when comparing the fit of the two models, the likelihood-ratio test statistic, *D*, was 131.88 with 5 degrees of freedom, which indicated a significantly better fit at $p \leq 0.05$ where the critical value for X^2 distributions (df = 5) is = 11.07 (Devore, 2004, p. 745). *D* was calculated using the following equation (Field, 2013, pp. 763-764):

$$D = 2 \times (\text{log-likelihood}_{\text{Model 2}} - \text{log-likelihood}_{\text{Model 1}})$$
$$= (\text{likelihood ratio } X^2{}_{\text{Model 2}}) - (\text{likelihood ratio } X^2{}_{\text{Model 2}})$$

These results, indicating the improved fit of Model 2 over Model 1, confirmed that as a group the measurable streetscape qualities related to walkability added significantly to the explanatory power of the models. This suggested that streetscape qualities should be considered in future models linking measures of the built environment related to walkability to pedestrian activity.

4.6.2 Significance of Model Variables

As noted earlier in Section 4.4, several of the D variables tested resulted in the expected positive relationships to the average pedestrian counts at statistically significant levels ($p \leq 0.05$), including buffer FAR, population density (Model 1 only), land-use entropy (Model 1 only), street segment length, and Walk Score. The only exception was distance to transit, which was statistically significant ($p \leq 0.05$) but had a negative relationship to average pedestrian counts. This was expected because as one moves further away from transit stops (i.e., the values of distance to transit get larger), one is more likely to choose an alternative to non-motorized forms of transport.

Buffer population density (Model 2 only), land-use entropy (Model 2 only), intersection density, proportion of four-way intersections, and average household size were nonsignificantly related ($p > 0.05$) to average pedestrian counts. While similar studies (Ameli et al., 2015; Ewing & Clemente, 2013b) have shown that intersection density, proportion of four-way intersections, and land-use entropy variables were similarly nonsignificant ($p > 0.05$), these results were surprising, as these variables have been shown to be strongly associated with household level travel studies (Ewing & Cervero, 2010). Some of the differences between the results in this study and those found in the literature may stem from the fact that this study specifically examines the relationship between streetscape qualities and pedestrian counts, as opposed to explaining individual walking trips. Additionally, upon further examination of the variables, some exhibited only slight variability. For example, the mean ± standard deviation for the average household size was 2.05 ± 0.31. Where there is only slight variation in the variable, it is often nonsignificant.

Despite some of the control variables showing nonsignificant relationships to pedestrian activity, two of the streetscape qualities, imageability and transparency, added significantly to the explanatory power of Model 2 and showed positive and significant relationships to pedestrian activity ($B = 0.18$, $p = 0.02$; and $B = 0.29$, $p = 4.60E-14$ respectively). This represents a novel finding, as it stands in contrast with previous results from the only other known study of its kind conducted on a city-wide scale[34] in New York City (Ewing & Clemente, 2013b). In that preliminary study, transparency was the only streetscape quality with a statistically significant ($p \leq 0.05$) relationship to pedestrian activity.

Transparency, defined in this study as "the degree to which people can see or perceive what lies beyond the edge of a street and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street" (Ewing & Handy, 2009, p. 78), was measured as a function of proportion of first floor windows, proportion of active uses buildings, and

[34] As noted in Section 2.3.2, a similar study was also conducted in Salt Lake City (SLC) by Ameli et al. (2015), which showed that both imageability and transparency were statistically significant ($p \leq 0.05$). However, Ameli et al.'s study was constrained geographically to the downtown area of SLC (just under 1 square mile or around 629 acres) and limited to a sample size of 179 sample street segments. By comparison, the case study area in this study was approximately 175 square kilometers (around 67.5 square miles or just over 43,243 acres) and $n = 693$ samples street segments.

proportion of the street wall[35] (see Figure 29 and Figure 30). Not only was transparency statistically significant ($p = 4.60\text{E-}14$) after controlling for D variables, but it also had the greatest significance of any other variable accounted for in the negative binomial generalized linear regression model. These results suggested that regardless of other standard control variables, including distance to transit ($p = 1.10\text{E-}12$), (Walk Score) destination accessibility ($p = 1.90\text{E-}05$), and floor area ratio ($p = 8.39\text{E-}04$), transparency was an important variable in modeling the relationship between built environment measures related to walkability and pedestrian activity.

Imageability, defined in this study as, "the quality of a place that makes it distinct, recognizable and memorable" (Ewing & Handy, 2009, p. 73), was measured as a function of proportion of historic buildings, number of courtyards/plazas/parks, presence of outdoor dining, number of buildings with non-rectangular shapes, noise level, number of major landscape features, and number of buildings with identifiers[36] (see Figure 31, Figure 32, and Figure 33). Similar to transparency, imageability was also shown to be a significant factor ($p = 0.02$)

---

[35] See Section 3.4.1.5 and Appendix D for more details on the transparency variable and how it was measured in this study.
[36] See Section 3.4.1.2 and Appendix D for more details on the imageability variable and how it was measured in this study.

Figure 29 – Active street with windows along a street wall contributing to transparency quality (Location: George St.)

Figure 30 – Raised first-floor windows well above the street level and view of the pedestrian, which do not contribute to transparency quality (Location: Blythswood Sq.)

Figure 31 – A building with identifying features (e.g., “convenience store”), indicating its first-floor use and contributing to the imageability quality (Location: High St.)

Figure 32 – Street with outdoor dining, which contributes to imageability quality

Figure 33 – Street with approximately 90 per cent of its building frontage (on both sides) occupied by historic buildings, contributing to imageability (Location: Bell St.)

in modeling the relationship between built environment measures related to walkability and pedestrian activity, though not as significantly as other variables included in the models.

4.6.3 A Note on the Effect Sizes of Model Variables

Table 44 presented the negative binomial regression coefficients for each of the control and predictor variables included in the two-step regression models. These coefficients, or *B* values, represented a measure of effect size and can be interpreted as follows: for a one unit change in the control/predictor variable, the difference in the logs of expected counts of the dependent variable (i.e., the average pedestrian counts) is expected to change by the respective regression coefficient, or *B* value, given the other control/predictor variables in the model are held constant. For example, in Table 44, the *B* value for transparency (Q_4) was 0.73. This meant that for every one unit increase in transparency scores, the difference in the logs of the expected average pedestrian counts would be expected to increase by 0.73, while holding the other variables constant. Given that the units for the control and predictor variables included in this model are different[37],

[37] For example, intersection density is measured in units of number of intersections within the 400 m buffer around each sample street segment divided by the gross area of the buffer in square km. While, transparency is measured in integer units according to the best fit models reported in Section 3.4.

comparing the relative effects of the independent and control variables on the dependent variable is difficult. However, these *B* values do still allow for an understanding of the individual effect of the control/predictor variables on the dependent variation (average pedestrian counts).

4.6.4 Additional Negative Binomial Generalized Linear Regression Models

For further analysis, two additional models were generated to compare against the control-only model (Model 1). The first was a simplified version of Model 2, containing only the control and independent variables that entered into Model 2 at significant levels ($p \leq 0.05$). The second was an adaptation of Model 2 whereby the independent variables (streetscape qualities) were substituted with individual streetscape features that were statistically significant ($p \leq 0.05$) in modeling pedestrian activity. These additional models provided further confirmation of model fits and highlighted the importance of individual streetscape features.

4.6.4.1 Simplification of Model Using Only Significant Control Variables (D Variables) and Independent Variables (Streetscape Qualities)

A simplified version of Model 2 (see Table 50), was generated using only the control variables (D variables) and independent variables (streetscape qualities) that entered significantly into Model 2 ($p \leq 0.05$).

Table 50 – Negative binomial generalized linear regression model, with only control and independent variables that entered into Model 2 at significant levels ($p \leq 0.05$)

Model 3						
Parameter	**B**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**	
			Lower	*Upper*	*Wald Chi-Square*	*p-value*
(Intercept)	-3.79	0.28	-4.35	-3.23	177.07	0.001<
D_1.1	0.33	0.08	0.18	0.49	17.89	2.30E-05
D_3.3	0.01	1.47E-03	2.66E-03	0.01	14.26	2.34E-05
D_4	0.02	3.90E-03	0.01	0.03	27.13	1.60E-04
D_5	-0.01	6.53E-04	-0.01	-3.59E-03	55.56	1.90E-07
Q_1	0.13	0.06	0.02	0.24	5.37	9.05E-14
Q_4	0.69	0.08	0.54	0.84	79.06	2.05E-02
(Negative binomial)	0.29	0.05	0.21	0.41		

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit
Independent variables: Q_1, Imageability; Q_4, Transparency

In this model, Model 3, all of the relationships with pedestrian activity remained the same. Similarly, Model 3 showed an improvement in the predictive power over Model 1 (see Table 51), where the likelihood-ratio test statistic, *D*, when compared with Model 1, was 126.53 with 3 degrees of freedom.

Table 51 – Likelihood ratio X^2 test results for Model 3

Model 3		
Likelihood Ratio X^2	**df**	**p-value**
522.81	6	0.001<

This indicated a significantly better fit at $p \leq 0.05$ where the critical value for X^2 distributions (df = 3) is = 7.815 (Devore, 2004, p. 745). However, when Model 3 was compared to Model 2, the likelihood-ratio test statistic, *D*, was only 5.34 with 8 degrees of freedom, indicating a nonsignificantly better fit at $p \leq 0.05$, where the critical value for X^2 distributions is 15.507 (Devore, 2004, p. 745).

Tests for multicollinearity (see Table 52) and spatial autocorrelation (see Figure 34) were also conducted and used to confirm that there was no redundancy of variables or spatial autocorrelation in the residuals in Model 3.

Overall, the results of the simplified negative binomial regression model (Model 3) confirmed that a model, based only on the significant ($p \leq 0.05$) control and independent variables from Model 2 could add significantly to the explanatory power of models. This is an important finding, as a

Table 52 – Multicollinearity statistics for Model 3

Variable	Collinearity Statistics	
	Tolerance	*VIF*
D_1.1	0.46	2.16
D_3.3	0.92	1.09
D_4.1	0.47	2.13
D_5	0.98	1.03
Q_1.1	0.59	1.71
Q_4	0.50	1.98

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit
Independent variables: Q_1, Imageability; Q_4, Transparency

simplified model may help streamline similar studies in the future (e.g., by reducing the time to collect and analyze street segment samples), aimed at modeling the relationship between measures of the built environment related to walkability and pedestrian activity. In statistical parlance, this is referred to as *parsimony*, as Field explained:

> *"[W]hen building a model we should strive for parsimony. In a scientific context, parsimony refers to the idea that simpler explanations of a phenomenon are preferable to complex ones. The statistical implication of using a parsimony heuristic is that models be kept as simple as possible. In other words, do not include predictors unless they have explanatory benefit"* (2013, p. 768)

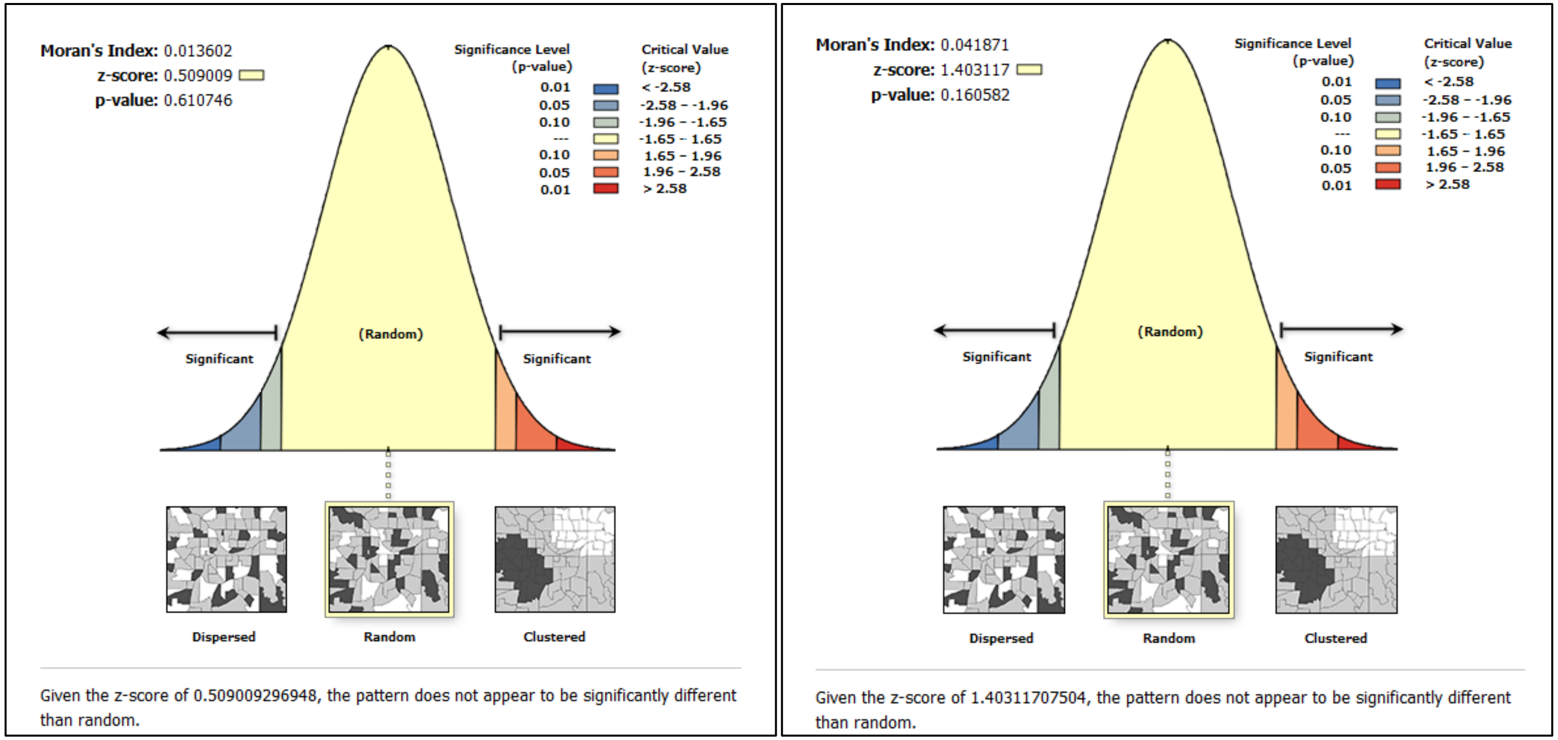


Figure 34 – Model 3 ArcGIS spatial autocorrelation report for zone of indifference conceptualization (left) and distance band conceptualization using spatial weights matrix (right)

4.6.4.2 Adaptation of Model Using Control Variables (D Variables) and Significant Independent Variables (Streetscape Features)

Though the focus of this study is on the relationship between streetscape qualities and pedestrian activity, an additional model (see Table 53) was created to relate streetscape features (comprised by the measured streetscape qualities) directly to average pedestrian counts. In this model, Model 4, the control variables (D variables) remained the same, while the earlier independent variables (streetscape qualities) were changed for streetscape features that entered into the model at significant levels ($p \leq 0.05$).

The three streetscape features that were included in the model were the number of buildings with identifiers (included in the measure of imageability), the proportion of street-level façade with windows (included in the measure of transparency), and the proportion of active use buildings (included in the measure of transparency). The number of buildings with identifiers variable ranged from 0 to 25, with a mean ± standard deviation of 1.54 ± 2.95. The proportion of street-level façade with windows variable ranged from 0 to 1, with a mean ± standard deviation of 0.25 ± 0.27. The

Table 53 – Comparison of model relating streetscape features directly to average pedestrian counts

	Model 1						Model 4					
			95% Wald Confidence Interval		Hypothesis Test				95% Wald Confidence Interval		Hypothesis Test	
Parameter	**B**	**Std. Error**	*Lower*	*Upper*	*Wald Chi-Square*	*p-value*	**B**	**Std. Error**	*Lower*	*Upper*	*Wald Chi-Square*	*p-value*
(Intercept)	-2.41	0.56	-3.52	-1.31	18.26	1.90E-05	-2	0.49	-2.96	-1.05	16.82	4.12E-05
D_1.1	0.46	0.12	0.23	0.69	15.38	8.80E-05	0.31	0.09	0.14	0.48	12.46	4.15E-04
D_1.2	0.05	0.02	0.02	0.09	7.41	0.01	0	0.02	-0.03	0.04	0.15	0.7
D_2	0.67	0.35	-0.01	1.36	3.69	0.05	0.22	0.31	-0.39	0.82	0.48	0.49
D_3.1	-3.27E-04	1.32E-03	-2.91E-03	2.26E-03	0.06	0.8	3.80E-05	1.13E-03	-2.18E-03	2.25E-03	1.13E-03	0.97
D_3.2	0.57	0.81	-1.02	2.15	0.49	0.49	0.01	0.71	-1.38	1.4	1.16E-04	0.91
D_3.3	5.28E-03	1.59E-03	2.17E-03	0.01	11.06	8.81E-04	0.01	1.43E-03	3.55E-03	0.01	19.8	8.60E-06
D_4	0.03	4.87E-03	0.02	0.04	38.28	6.13E-10	0.02	4.29E-03	0.01	0.03	22.18	2.48E-06
D_5	-0.01	7.10E-03	-0.01	-3.92E-03	55.94	7.46E-14	-4.31E-03	6.52E-04	-0.01	-3.04E-03	43.84	3.56E-11
D_6	-0.21	0.2	-0.6	0.19	1.06	0.3	-0.15	0.17	-0.49	0.19	0.74	0.39
F_1.4							0.05	0.01	0.03	0.08	14.07	1.76E-04
F_4.1							0.54	0.23	0.09	0.99	5.54	0.02
F_4.3							0.77	0.18	0.42	1.13	18.61	1.60E-05
Estimated Dispersion Coefficient	0.59	0.07	0.46	0.75			0.25	0.05	0.18	0.36		

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size
Independent variables: F_1.4, Number of buildings with identifiers (Imageability); F_4.1, Proportion of street-level façade with windows (Transparency); F_4.3, Proportion of active use buildings (Transparency)

proportion of active use buildings variable ranged from 0 to 1, with a mean ± standard deviation of 0.19 ± 0.35.

While the number of buildings with identifiers (B = 0.05, p = 1.76E-04), the proportion of street-level façade with windows (B = 0.54, p = 0.02), and the proportion of active use buildings (B = 0.77, p = 1.60E-05) were all positively and significantly related to average pedestrian counts, these individual streetscape features were not as significant as other standard D variables like the distance to transit (p = 3.56E-11) and (Walk Score) destination accessibility (p = 2.48E-06).

Overall, both models had significant likelihood ratio chi-squared (X^2) statistics ($p \leq 0.05$), indicating a good fit relative to the intercept-only, or "null," model without any predictor variables (see Table 54).

Table 54 – Likelihood ratio X^2 test results for Model 1 and Model 4

Model 1			**Model 4**		
Likelihood Ratio X^2	**df**	**p-value**	**Likelihood Ratio X^2**	**df**	**p-value.**
396.28	9	0.001<	556.42	12	0.001<

When comparing the fit of the two models, the likelihood-ratio test statistic, *D*, was 160.14 with 3 degrees of freedom, which indicated a significantly better fit at $p \leq 0.05$ where the critical value for X^2 distributions (df = 3) is = 7.82 (Devore, 2004, p. 745).

Tests for multicollinearity (see Table 55) and spatial autocorrelation (see Figure 35) were also conducted and used to confirm that there was no redundancy of variables or spatial autocorrelation in the residuals in Model 4.

Table 55 – Multicollinearity statistics for Model 4

Variable	Collinearity Statistics	
	Tolerance	*VIF*
D_1.1	0.34	2.91
D_1.2	0.44	2.29
D_2	0.81	1.23
D_3.1	0.56	1.79
D_3.2	0.89	1.13
D_3.3	0.95	1.05
D_4.1	0.37	2.69
D_5	0.92	1.09
D_6	0.75	1.33
F_1.4	0.41	2.43
F_4.1	0.36	2.81
F_4.3	0.31	3.28

Dependent Variable: Average pedestrian counts
Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size
Independent variables: F_1.4, Number of buildings with identifiers (Imageability); F_4.1, Proportion of street-level façade with windows (Transparency); F_4.3, Proportion of active use buildings (Transparency)

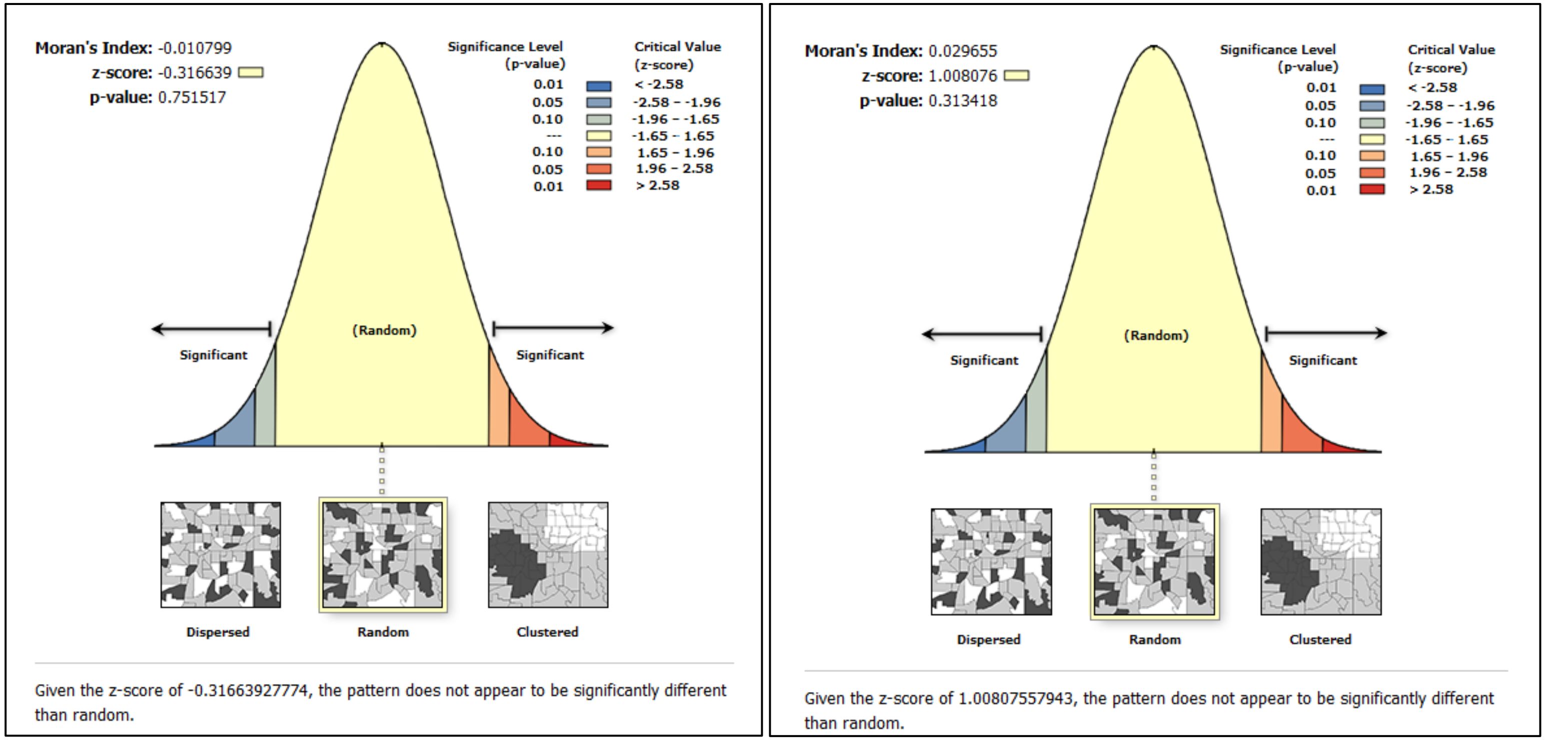


Figure 35 – Model 4 ArcGIS spatial autocorrelation report for zone of indifference conceptualization (left) and distance band conceptualization using spatial weights matrix (right)

Overall, these results indicated that individual streetscape features or groups of streetscape features may add significantly to the explanatory power of models. This is also an important finding, as urban designers often wish to know those specific features that may help contribute pedestrian activity. However, urban designers should be careful to avoid interpreting these results as certain streetscape features leading to a causal effect on increased pedestrian activity. Rather, they should be considered as part of and along with other significant factors, including streetscape qualities and other measures of the built environment related to walkability (e.g., the standard D variables). The following sections will provide more details on the implications of these results for further research and practice in the field of urban design, and important limitations.

4.6.5 Additional Considerations for Regression Analyses

As noted in Section 4.3, the distribution of the average pedestrian counts was positively skewed, positively kurtotic, and therefore non-normally distributed – i .e., the assumptions of an ordinary least squares (OLS) regression were violated. Additionally, as noted in Section 3.2, the purposive method used established for selecting the units of observation (i.e., the sample street segments) was used in lieu of a randomized selection, in an attempt to capture relevant and unique sample street segments (e.g., Buchanan Street, Great Western Road, London Road, etc.) that were most likely to attract pedestrian activity and be of the greatest importance to the local population due to the connection with the rest of the city. However, at the suggestion of Prof Robert Gifford (University of Victoria), further consideration was given to the potential effect of outliers in the dataset.

While determining outliers in multivariate analyses can be explored using a number of methods (e.g., residuals, leverage, and Cook's D statistics), it was suggested by Gifford that an outlier may be defined as sample street segments with unusually high pedestrian activity relative to the other sample street segments in the dataset (e.g., Buchanan Street). In keeping with this suggestion, a boxplot was generated (see Figure 36) to help identify potential outliers. Boxplots are useful for displaying several aspects of a dataset, including: (1) the interquartile range (IQR), that is the middle 50% of average pedestrian counts) represented by the tinted box; (2) the median score, represented by the solid black line in the tinted box; (3) the range of top 25% and bottom 25% of scores, represented by the whiskers; and (4) potential outliers, that is, scores that are 3 times the IQR, represented by the * symbol.

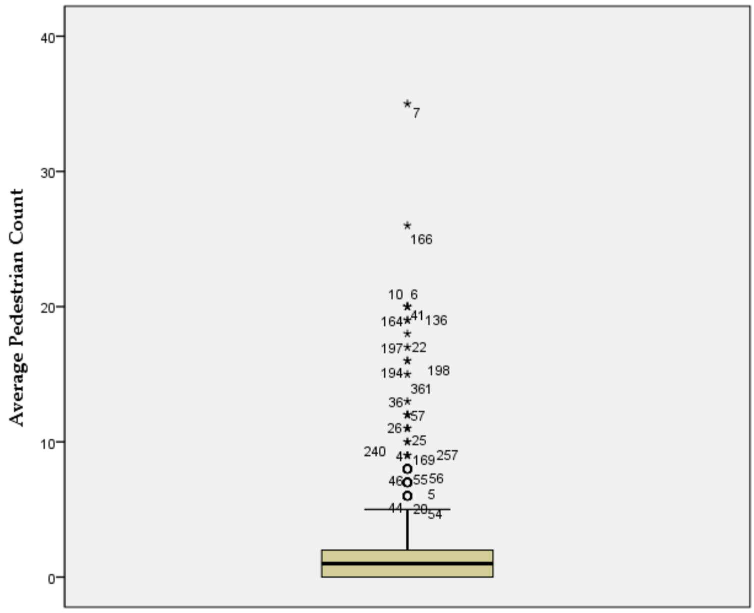


Figure 36 – Box plot of the dependent variable (average pedestrian counts)

After a visual inspection of the potential outliers in Figure 36 and consultation with a research supervisor, Dr. David Rowe, it was decided that sample street segments with average pedestrian counts greater than 9 (i.e., 3 times the IQR) would be excluded as outliers in an additional analysis of the data[38].

Two additional regression models were then generated (see Table 56) to compare the results after the exclusion of outliers using a two-step regression analysis.

38 Note, this excluded data collected from 23 sample street segments with average pedestrian counts great than 9, which included samples collected on streets such as Buchanan Street, Victoria Road, and Byers Road that typically receive higher volumes of pedestrian traffic given their proximity to shops and other local amenities.

Table 56 – Negative binomial generalized linear regression models (adjusted for outliers)

	Model 5						Model 6					
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test	
			Lower	*Upper*	*Wald Chi-Square*	*p-value*			*Lower*	*Upper*	*Wald Chi-Square*	*p-value*
(Intercept)	-1.55	0.53	-2.58	-0.51	8.59	3.38E-03	-2.38	0.50	-3.37	-1.40	22.52	2.08E-06
D_1.1	0.44	0.15	0.16	0.73	9.11	2.54E-03	0.38	0.13	0.12	0.64	8.38	3.80E-03
D_1.2	0.02	0.02	-0.03	0.06	0.55	0.46	-0.03	0.02	-0.07	0.01	1.56	0.21
D_2	0.66	0.32	0.03	1.28	4.16	0.04	0.47	0.30	-0.12	1.056	2.46	0.12
D_3.1	1.78E-04	1.22E-03	-2.57E-03	2.21E-03	0.02	0.88	2.83E-04	1.11E-03	-1.90E-03	2.46E-03	0.07	0.80
D_3.2	-0.49	0.75	-1.96	0.98	0.43	0.51	-0.48	0.70	-1.84	0.89	0.47	0.49
D_3.3	0.01	1.46E-03	1.66E-03	0.01	9.60	1.95E-03	0.01	1.40E-03	3.22E-03	0.01	18.21	1.98E-05
D_4	0.03	4.50E-03	0.02	0.04	40.36	2.11E-10	0.02	0.004.23E-03	0.01	0.03	19.10	1.23E-05
D_5	-0.01	6.65E-04	-6.02E-03	-3.42E-03	50.47	1.21E-12	-0.01	6.49E-04	-0.01	-3.25E-03	48.63	3.09E-12
D_6	-0.46	0.20	-0.86	-0.06	5.01	0.03	-0.46	0.19	-0.83	-0.09	6.03	0.01
Q_1							0.07	0.08	-0.09	0.22	0.77	0.38
Q_2							0.02	0.06	-0.10	0.13	0.07	0.79
Q_3							-0.05	0.08	-0.20	0.10	0.38	0.54
Q_4							0.68	0.09	0.50	0.86	57.01	4.35E-14
Q_5							-0.06	0.09	-0.24	0.12	0.39	0.53
Estimated Dispersion Coefficient	0.33	0.07	0.22	0.49			0.15	0.05	0.08	0.28		

Dependent Variable: Average pedestrian counts

Control Variables: D_1.1, FAR; D_1.2, Population density; D_2, Land-use entropy; D_3.1, Intersection density; D_3.2, Proportion of four-way intersections; D_3.3, Street segment length; D_4, Walk Score; D_5, Distance to transit; D_6, Buffer average household size

Independent variables: Q_1, Imageability; Q_2, Enclosure; Q_3, Human scale; Q_4, Transparency; Q_5, Complexity

Overall, both Models 5 and 6 had significant ($p \leq 0.05$) likelihood ratio chi-squared (X^2) statistics, indicating a good fit relative to the intercept-only, or "null," model without any predictor variables (see Table 57).

Table 57 – Likelihood ratio X^2 test results for Model 5 and Model 6

Model 5			**Model 6**		
Likelihood Ratio X^2	**df**	**p-value**	**Likelihood Ratio X^2**	**df**	**p-value.**
294.77	9	0.001<	392.25	14	0.001<

Moreover, when comparing the fit of the two models, the likelihood-ratio test statistic, *D*, was 97.48 with 5 degrees of freedom, which indicated a significantly better fit at $p \leq 0.05$ where the critical value for X^2 distributions (df = 5) is = 11.07 (Devore, 2004, p. 745).

These results, indicating the improved fit of Model 6 over Model 5, confirmed that, despite the removal of potential outliers, the measurable streetscape qualities related to walkability still added significantly to the explanatory power of the models. This suggested that streetscape qualities should still be considered in future models linking measures of the built environment related to walkability to pedestrian activity.

4.6.6 Implications for the Research and Practice of Urban Design

4.6.6.1 Implications for Research

This study adds to the literature on the relationship between measures of the built environment related to walkability and pedestrian activity in several ways. First, considering this case study was conducted in Glasgow, this study represents the first of its kind conducted outside of the United States and is intended to address previous concerns regarding generalizability and homogeneity of environmental patterns (Ameli et al., 2015, p. 406; Ewing & Clemente, 2013b, p. 98). Though the results of this study are unique to Glasgow, it is intended to shed light on similar trends within other post-industrial European cities.

Secondly, this study employed a more rigorous methodology for data collection and analysis. Novel methods of primary data collection using on-street video recording were developed and validated, and stricter sampling parameters were established in order to create a more standardized method of data collection and address previous concerns regarding the variability in the day and time of pedestrian counts (Ewing & Clemente, 2013b, p. 98). Though limited counts still remains a threat to the reliability of the data collected, every effort was made to try to get a representative sampling of typical daily flow.

Lastly, this study also applied rigorous controls for spatial autocorrelation and multicollinearity that have not always been used in past studies (e.g., Ewing & Clemente, 2013a). These controls validated the results of the negative binomial regression models. For a discussion of further research, building upon this study, see Section 5.3.

4.6.6.2 Implications for Practice

The results of this research study pose several implications for practice. While traditional aspects of urban planning and design (e.g., building density, transit accessibility, etc.) remain important to pedestrian activity and the function of the city itself, the careful design of streets may also contribute significantly to pedestrian activity or "life" on the street. This idea has been well-reflected in policy statements by the Scottish Government (Scottish Government, 2010, 2011). The Scottish Government's policy statement on street design, *Designing Streets*[39], highlighted six qualities to be used as a framework for "good street design" (Scottish Government, 2010, p. 11). These

[39] Importantly, Glasgow City Council's own *Design Guide for New Residential Areas* (Glasgow City Council, 2013) builds upon and interprets the guidance detailed in *Designing Streets*.

qualities are *distinctive*, *safe and pleasant*, *easy to move around*, *welcoming*, *adaptable*, and *resource efficient*, which share many parallels with the streetscape qualities measured in this study, including transparency and imageability.

With regards to the quality of transparency, *Designing Streets* stressed the importance of pedestrian streets being "overlooked with active frontages" (p. 23), providing direct frontage access to buildings as a way to "generate activity and positive relationship between the street and its surroundings" (p. 37), the advantages of putting cars underground as a way to "[preserve] the street frontage", and avoiding "parking within the front curtilage…as it breaks up the frontage" (p. 42). However, there is no specific mention of the importance of street-level windows. Future iterations of the policy statement may benefit from more explicit reference to the importance of street-level windows, as they are an important component of transparency and have been shown to relate directly to pedestrian activity in this study.

With regards to the quality of imageability, *Designing Streets* stresses the importance of pedestrian streets being "enhanced with punctuations of public space" including "parks, green edges or formal and informal squares" (p. 25), having "provision of views and vistas, landmarks, gateways and focal points" as a means of orientation and creating visual interest (p. 25), lining streets with buildings that help create a "sense of place" by promoting "local distinctiveness" (p. 7), and designing to "mitigate noise pollution" (p. 25). However, there is no specific mention of the importance of buildings with identifiers that help reveal a building's street-level use. Future iterations of the policy statement may benefit from more explicit reference to the importance of buildings with identifiers, as they are an important component of imageability and have been shown to relate directly to pedestrian activity in this study.

4.6.7 Limitations of the Results

As suggested in the previous sections discussing the results, this study is not without its limitations. First, pedestrian counts at each sample street segment were limited given the geographical scale of the study. One recommendation for future research would be to conduct longer standardized counts on a subset of the samples in order to get a longitudinal picture of pedestrian activity at a given location. Technology now exists to track pedestrian activity remotely using fixed pedestrian trackers, which can also provide more detail on types of pedestrian activity and patterns over time.

Secondly, while the results of this study are intended to shed light on potential relationships between streetscape qualities and pedestrian activity in other post-industrial European cities, the results of this study are unique to Glasgow and more specifically to the most central, pedestrian street segments from each of Glasgow's SIMD datazones. Another recommendation for future research would be to conduct this study in other post-industrial European cities, especially those in the UK (e.g., Manchester) or Scotland in particular.

Lastly, this study focuses only on correlations between measures of the built environment linked to walkability and pedestrian activity. It does not prove causality. Future research exploring the relationship between qualities of the built environment related to walkability and measures of pedestrian activity should also include interviews and/or surveys that seek to understand what interests and motivates people to walk along certain streets. A valuable complement to this study would be to conduct a representative interview and/or survey of local citizens on a subset of the samples to understand how personal preferences align with measured streetscape qualities. Likewise, technology also exists to simulate walking through a virtual environment and track eye movements of participants. Using the video samples collected in this study and eye-tracking technology, it would be possible to identify additional streetscape features that capture the attention of observers, which are not covered in the current index of streetscape features and qualities – thus improving researcher's ability to measure what really matters in relation to pedestrian activity.

CHAPTER 5. CONCLUSIONS

When Jan Gehl coined the phrase “life between buildings” he defined it by writing, “[l]ife between buildings is not merely pedestrian traffic or recreational or social activities. Life between buildings comprises the entire spectrum of activities, which combine to make communal spaces in cities and residential areas meaningful and attractive” (Gehl, 1987, p. 14). Understanding the forces that influence this activity or “life” between buildings remains one of the fundamental challenges in the field of urban design. Macroscale measures of walkability and microscale measures of individual streetscape features have formed the basis for much of the evidence linking the built environment and pedestrian activity. However, these measures alone do not reflect pedestrians’ overall perceptions of streetscape qualities. The importance of perceptual streetscape qualities, and their relationship to pedestrian activity, has been written about extensively in the urban design literature. Yet, only a handful of limited preliminary studies have ever tried to address this gap in the research. The primary purpose of this study was to improve upon the limitations of past studies, and further test the validity of using perceptual qualities in walkability studies by modeling the relationship between objective measures of streetscape qualities and pedestrian activity in Glasgow, Scotland, while controlling for macroscale measures of walkability.

5.1 Summary of Findings

From the onset of this study, it was argued that a greater understanding of the relationship between the built environment and pedestrian activity could be gained by adopting a probabilistic theoretical perspective. Applied to this this study, probabilistic theory held that one would expect independent measures of streetscape qualities related to walkability to help explain overall patterns of pedestrian activity, while controlling for other macroscale factors of walkability. Based on the results of past studies, the following hypotheses were made:

1. Collectively, measures of the streetscape qualities add significantly ($p \leq 0.05$) to the overall explanatory power of walkability models, when controlling for macroscale measures of walkability (i.e., measures of important D variables).

2. Individually, measures of streetscape qualities are directly and significantly ($p \leq 0.05$) related to average pedestrian counts

(dependent variable), when controlling for macroscale measures of walkability (i.e., measures of important D variables).

3. Measures of streetscape qualities are of equal or greater significance in explaining measures of pedestrian activity, when compared to other known built environment correlates of pedestrian activity – i.e., macroscale measures of walkability (D variables).

To compare the relationship between the control variables (D variables) and the independent variables (streetscape quality) with the dependent variable (average pedestrian counts), two negative binomial regression models were generated based on primary data collected from 693 central, pedestrian street segments throughout Glasgow and secondary data analyzed using GIS (see Table 44). Overall, several of the D variables resulted in the expected positive relationships to the average pedestrian counts at statistically significant levels ($p \leq 0.05$). However, when comparing the fit of the control-only model and the model with both the control and independent variables, the results ($D = 131.88$, $df = 5$) indicated that the objective measures of streetscape qualities related to walkability added significantly ($p \leq 0.05$) to the explanatory power of the models, validating the first hypothesis. These results suggested that streetscape qualities should be considered in future models linking measures of the built environment related to walkability to pedestrian activity.

Additionally, two of the individual streetscape qualities – imageability and transparency – added significantly ($p \leq 0.05$) to the explanatory power of the walkability models, and showed positive and significant relationships to pedestrian activity ($B = 0.18$, $p = 0.02$; and $B = 0.29$, $p = 4.60\text{E-}14$ respectively), validating the second hypothesis. This represented a novel finding, as it stands in contrast with previous results from the only other known study of its kind conducted on a city-wide scale[40] in New York City (Ewing & Clemente, 2013b).

Transparency, defined in this study as "the degree to which people can see or perceive what lies beyond the edge of a street and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street" (Ewing & Handy, 2009, p. 78), was measured as a function of proportion of first floor windows, proportion of active uses buildings, and

[40] As noted in Section 2.3.2, a similar study was also conducted in Salt Lake City (SLC) by Ameli et al. (2015), which showed that both imageability and transparency were statistically significant ($p \leq 0.05$). However, Ameli et al.'s study was constrained geographically to the downtown area of SLC (just under 1 square mile or around 629 acres) and limited to a sample size of 179 sample street segments. By comparison, the case study area in this study was approximately 175 square kilometers (around 67.5 square miles or just over 43,243 acres) and $n = 693$ samples street segments.

proportion of the street wall. Not only was transparency statistically significant (p = 4.60E-14) after controlling for D variables, but it also had the greatest significance of any other variable accounted for in the negative binomial generalized linear regression model, validating the third hypothesis. These results suggested that regardless of other standard control variables, including distance to transit (p = 1.10E-12), (Walk Score) destination accessibility (p = 1.90E-05), and floor area ratio (p = 8.39E-04), transparency was an important variable in modeling the relationship between built environment measures related to walkability and pedestrian activity.

Imageability, defined in this study as, "the quality of a place that makes it distinct, recognizable and memorable" (Ewing & Handy, 2009, p. 73), was measured as a function of proportion of historic buildings, number of courtyards/plazas/parks, presence of outdoor dining, number of buildings with non-rectangular shapes, noise level, number of major landscape features, and number of buildings with identifiers. Similar to transparency, imageability was also shown to be a significant factor (p = 0.02) in modeling the relationship between built environment measures related to walkability and pedestrian activity, though not as significantly as other variables included in the models.

5.2 Notes on Causality and Moving Towards Probabilism

While this study identified unique correlations between macroscale and microscale measures of the built environment and pedestrian activity, it cannot explain causality. That is, the results of this study merely explain what is, not why. Several limitations related to the methodology and interpretation of the results from this study were noted in the previous chapters. However, it is hoped that as an instrumental case the results from this study might be used in future comparisons to studies conducted in similar types of cities. By continuing to identify the patterns in the relationship between streetscape qualities (Lockton, 2012) and pedestrian activity, the closer future models will come to probabilism and enhancing the ability of urban designers to understand what the effective environment of people will be when the built environment is design in a particular way (Lang, 1987).

5.3 Notes on Future Studies

As noted above in Section 4.6.4.1, this study adds to the walkability literature in several ways that can be built upon in future studies to increase the understanding of the relationship between streetscape qualities (related to walkability) and pedestrian activity. This study was the first of its kind conducted outside of the United States, and was is intended to address previous concerns regarding generalizability and homogeneity of environmental patterns identified in previous studies by Ameli et al. (2015, p. 406) and Ewing and Clemente (2013b, p. 98). Though the results of this study are unique to central, pedestrian streets in Glasgow, as an instrumental case study it was intended to shed light on potential trends within similar post-industrial European cities. One recommendation for future studies would be to conduct a similar study in other post-industrial European cities, especially those in the UK (e.g., Manchester) or Scotland in particular.

This study also employed a more rigorous methodology for data collection and analysis. Novel methods of primary data collection using on-street video recording were developed and validated, and stricter sampling parameters were established in order to create a more standardized method of data collection across a city-wide geography, addressing previous concerns regarding the variability in the day and time of pedestrian counts in the study by Ewing and Clemente (2013b, p. 98). Though the limited number of pedestrian counts still remains a threat to the reliability of the pedestrian activity data collected in this study, every effort was made to get a representative sampling of typical daily flow and validate measures against other samples taken from Google Street View and Bing Streetside imagery sources. Another recommendation for future studies would be to conduct longer standardized counts on a diverse (with respect to range of qualities) subset of the samples in order to get a longitudinal picture of pedestrian activity at selected locations. Technology now exists to track a range of pedestrian activities using remote sensors fixed at on-street locations throughout the city. The author of this study has already started to explore the future use of tools, such as "placemeters" (Placemeter Inc., 2016) that use on-street sensors to remotely track the movements of pedestrians over time, such as volumes (numbers of people or flows), walking direction, and dwell time (stopping time). This type of technology could also potentially unlock the ability to understand pedestrian activity patterns in relation to unique design interventions on the street aimed at improving streetscape qualities.

Lastly, this study focuses on correlations between measures of the built environment linked to walkability and pedestrian activity. A valuable complement to this study would be to include additional interview or surveys of local citizens to better understand how personal preferences, motivations, and interests align with measured streetscape qualities. Likewise, technology also exists to simulate walking through a virtual environment and track eye movements of participants as they conduct virtual walk-throughs. Using the video samples collected in this study and eye-tracking technology, it may be possible to identify additional physical features that capture the attention of observers, yet are not represented in the current index of streetscape features and qualities.

5.4 Conclusion

Streets are one of the most important, permanent, and defining elements of the public realm. They provide a link between daily amenities and a context for public life. Over the past several years, the fields of urban design and public health have united under a common interest in understanding the walkability of streets as it relates to health and efforts to curb vehicle miles traveled and reduce sprawl and emissions. Understanding the nature of the relationship between measures of the built environment and pedestrian activity has remained one of the fundamental challenges within the field of urban design. Until recently, macroscale measures of walkability and microscale measures of individual streetscape features have formed the basis for much of the evidence describing the relationship between the built environment and pedestrian activity. However, this study added to the understanding of this relationship by demonstrating that objective measures of streetscape qualities added significantly ($p \leq 0.05$) to the explanatory power of walkability models, and that streetscape qualities, such as imageability and transparency, in individually added significantly ($p \leq 0.05$) to the explanatory power of walkability models.

REFERENCES

REFERENCES

Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., & Angel, S. (1977). *A Pattern Language*. New York: Oxford University Press.

Ameli, S. H., Hamidi, S., Garfinkel-Castro, A., & Ewing, R. (2015). Do Better Urban Design Qualities Lead to More Walking in Salt Lake City, Utah? *Journal of Urban Design, 20*(3), 393-410.

Bader, M. D. M., Mooney, S. J., Lee, Y. J., Sheehan, D., Neckerman, K. M., Rundle, A. G., & Teitler, J. O. (2015). Development and deployment of the Computer Assisted Neighborhood Visual Assessment System (CANVAS) to measure health-related neighborhood conditions. *Health & Place, 31*, 163-172. doi:http://dx.doi.org/10.1016/j.healthplace.2014.10.012

Badland, H., Opit, S., Witten, K., Kearns, R., & Mavoa, S. (2010). Can Virtual Streetscape Audits Reliably Replace Physical Streetscape Audits? *Journal of Urban Health, 87*(6), 1007-1016. doi:10.1007/s11524-010-9505-x

Badoe, D. A., & Miller, E. J. (2000). Transportation–land-use interaction: empirical findings in North America, and their implications for modeling. *Transportation Research Part D: Transport and Environment, 5*(4), 235-263. doi:http://dx.doi.org/10.1016/S1361-9209(99)00036-X

Bauman, A., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., & Martin, B. W. (2012). Correlates of physical activity: why are some people physically active and others not? *The Lancet, 380*(9838), 258-271. doi:http://dx.doi.org/10.1016/S0140-6736(12)60735-1

Bento, A. M., Cropper, M., Mobarak, A. M., & Vinha, K. (2003). The impact of urban spatial structure on travel demand in the United States. *World Bank policy research working paper*(3007).

Blumenfeld, H. (1953). Scale in civic design. *Town Planning Review, 24*(1), 35.

Boarnet, M. G., Day, K., Alfonzo, M., Forsyth, A., & Oakes, M. (2006). The Irvine–Minnesota Inventory to Measure Built Environments: Reliability Tests. *American Journal of Preventive Medicine, 30*(2), 153-159.e143. doi:http://dx.doi.org/10.1016/j.amepre.2005.09.018

Boarnet, M. G., Forsyth, A., Day, K., & Oakes, J. M. (2011). The Street Level Built Environment and Physical Activity and Walking: Results of a Predictive Validity Study for the Irvine Minnesota Inventory. *Environment and Behavior, 43*(6), 735-775. doi:10.1177/0013916510379760

Boarnet, M. G., Greenwald, M., & McMillan, T. E. (2008). Walking, Urban Design, and Health: Toward a Cost-Benefit Analysis Framework. *Journal of Planning Education and Research, 27*(3), 341-358. doi:10.1177/0739456x07311073

Boarnet, M. G., Joh, K., Siembab, W., Fulton, W., & Mai Thi Nguyen. (2011). Retrofitting the Suburbs to Increase Walking: Evidence from a Land-use-Travel Study. *Urban Studies, 48*(1), 129-159. doi:10.1177/0042098010364859

Brand, S. (1994). *How Buildings Learn: What Happens After They're Built* (Reprint from Viking (1994) ed.). London: Phoenix Illustrated (1997).

Brennan Ramirez, L. K., Hoehner, C. M., Brownson, R. C., Cook, R., Orleans, C. T., Hollander, M., . . . Wilkinson, W. (2006). Indicators of Activity-Friendly Communities: An Evidence-Based Consensus Process. *American Journal of Preventive Medicine, 31*(6), 515-524. doi:http://dx.doi.org/10.1016/j.amepre.2006.07.026

Brewer, E. W., & Kuhn, J. (2010). Causal-Comparative Design. In N. J. Salkind (Ed.), *Encyclopedia of Research Design* (pp. 125-132). Thousand Oaks, CA: SAGE Publications, Inc.

British Heart Foundation National Centre. (2013). *Economic costs of physical inactivity: Evidence briefing*. Retrieved from

Broady, M. (1972). Social Thoery in Architectural Design. In R. Gutman (Ed.), *People and Buildings* (pp. 170-185). New York: Basic Books, Inc., Publishers. (Reprinted from: Reprinted from Maurice Broady, "Social Theory of Architectural Design," *Arena*, The Architectural Association Journal, London, 81, no. 898 (January 1966): 149-154).

Brownson, R. C., Hoehner, C. M., Brennan, L. K., Cook, R. A., Elliott, M. B., & McMullen, K. M. (2004). Reliability of 2 instruments for auditing the environment for physical activity. *J Phys Act Health, 1*, 191-208.

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A., & Sallis, J. F. (2009). Measuring the Built Environment for Physical Activity: State of the Science. *American Journal of Preventive Medicine, 36*(4, Supplement), S99-S123.e112. doi:http://dx.doi.org/10.1016/j.amepre.2009.01.005

Bruce, R. (1945). *First planning report to the Highways and Planning Committee of the Corporation of the City of Glasgow*: Glasgow: Corporation of the City of Glasgow.

Buchanan, R. (1985). Declaration by Design: Rhetoric, Argument, and Demonstration in Design Practice. *Design Issues, 2*(1), 4-22. doi:10.2307/1511524

Cain, K. L., Millstein, R. A., Sallis, J. F., Conway, T. L., Gavand, K. A., Frank, L. D., . . . Adams, M. A. (2014). Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). *Social Science & Medicine, 116*, 82-92.

Cao, X., Handy, S., & Mokhtarian, P. (2006). The Influences of the Built Environment and Residential Self-Selection on Pedestrian Behavior:

Evidence from Austin, TX. *Transportation, 33*(1), 1-20. doi:10.1007/s11116-005-7027-2
Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings. *Transport Reviews, 29*(3), 359-395. doi:10.1080/01441640802539195
Carr, L. J., Dunsiger, S. I., & Marcus, B. H. (2011). Validation of Walk Score for estimating access to walkable amenities. *Br J Sports Med, 45*(14), 1144-1148. doi:10.1136/bjsm.2009.069609
Cervero, R. (2003). The built environment and travel: evidence from the United States. *European Journal of Transport and Infrastructure Research, 3*(2), 119-137.
Cervero, R. (2006). Alternative Approaches to Modeling the Travel-Demand Impacts of Smart Growth. *Journal of the American Planning Association, 72*(3), 285-295. doi:10.1080/01944360608976751
Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment, 2*(3), 199-219. doi:http://dx.doi.org/10.1016/S1361-9209(97)00009-6
Chartered Institution of Highways and Transportation. (2010). *Manual for Streets 2: Wider Application of the Principles*. London: Chartered Institution of Highways and Transportation.
Cicchetti, D. V. (1994). Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological Assessment, 6*(4), 284-290. doi:10.1037/1040-3590.6.4.284
Clarke, P., Ailshire, J., Melendez, R., Bader, M., & Morenoff, J. (2010). Using Google Earth to conduct a neighborhood audit: Reliability of a virtual audit instrument. *Health & Place, 16*(6), 1224-1229. doi:http://dx.doi.org/10.1016/j.healthplace.2010.08.007
Clemente, O., Ewing, R., Handy, S., & Brownson, R. (2005). *Measuing Urban Design Qualities: An Illustrated Field Manual*. Retrieved from Princeton, NJ: http://activelivingresearch.org/sites/default/files/FieldManual_071605.pdf
Cliff, A. D., & Ord, J. K. (1975). The choice of a test for spatial autocorrelation *Display and analysis of spatial data* (pp. 54-77).
Cliff, A. D., & Ord, J. K. (1981). *Spatial processes: models & applications*: Taylor & Francis.
Clifton, K. J., Livi Smith, A. D., & Rodriguez, D. (2007). The development and testing of an audit for the pedestrian environment. *Landscape and*

Urban Planning, 80(1–2), 95-110. doi:http://dx.doi.org/10.1016/j.landurbplan.2006.06.008

Crane, R. (2000). The Influence of Urban Form on Travel: An Interpretive Review. *Journal of Planning Literature, 15*(1), 3-23. doi:10.1177/08854120022092890

Crucitti, P., Latora, V., & Porta, S. (2006). Centrality measures in spatial networks of urban streets. *Physical Review E, 73*(3), 036125.

Cullen, G. (1961). *The Concise Townscape*. New York: Architectural Press.

Day, K., Boarnet, M., Alfonzo, M., & Forsyth, A. (2006). The Irvine–Minnesota Inventory to Measure Built Environments: Development. *American Journal of Preventive Medicine, 30*(2), 144-152. doi:http://dx.doi.org/10.1016/j.amepre.2005.09.017

Department for Transport. (2007). *Manual for Streets*. London: Thomas Telford Publishing.

Design Council. (2014). Active by Design: Designing places for healthy lives. In D. Council (Ed.): Design Council.

Devore, J. L. (2004). *Probability and Statistics for Engineering and the Sciences*: Thomson-Brooks/Cole.

Doyle, S., Kelly-Schwartz, A., Schlossberg, M., & Stockard, J. (2006). Active Community Environments and Health: The Relationship of Walkable and Safe Communities to Individual Health. *Journal of the American Planning Association, 72*(1), 19-31. doi:10.1080/01944360608976721

Duany, A., & Plater-Zyberk, E. (1992). The second coming of the American small town. *Wilson Quarterly, 16*(1), 3-51.

Duany, A., Plater-Zyberk, E., & Speck, J. (2000). *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. New York: North Point Press.

Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011). Validation of Walk Score(®) for Estimating Neighborhood Walkability: An Analysis of Four US Metropolitan Areas. *International Journal of Environmental Research and Public Health, 8*(11), 4160-4179. doi:10.3390/ijerph8114160

Elsheshtawy, Y. (1997). Urban Complexity: Toward the Measurement of the Physical Complexity of Street-Scapes. *Journal of Architectural and Planning Research, 14*(4), 301-316.

Esri Inc. (2015). ArcGIS 10.4 for Desktop (Version 10.4). Redlands, California: Environmental Systems Research Institute,.

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., Chen, D., McCann, B., & Goldberg, D. (2008). *Growing Cooler: The Evidence on Urban Development and Climate Change*: ULI Washington, DC.

Ewing, R., & Cervero, R. (2001). Travel and the built environment: a synthesis. *Transportation Research Record: Journal of the Transportation Research Board*(1780), 87-114.
Ewing, R., & Cervero, R. (2010). Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association, 76*(3), 265-294.
Ewing, R., & Clemente, O. (2013a). Analysis and Final StepsMeasuring Urban Design: Metrics for Livable Places. In A. C. Nelson & R. Ewing (Series Eds.), Metropolitan Planning + Design. London: Island Press.
Ewing, R., & Clemente, O. (2013b). *Measuring Urban Design: Metrics for Livable Places*. London: Island Press.
Ewing, R., & Clemente, O. (2013c). Validation of Measures *Measuring Urban Design* (pp. 83-98). Washington: Island Press.
Ewing, R., Clemente, O., Handy, S., Brownson, R. C., & Winston, E. (2005). *Identifying and Measuring Urban Design Qualities Related to Walkability - Final Report*. Retrieved from Princeton, N.J.:
Ewing, R., Hajrasouliha, A., Neckerman, K. M., Purciel-Hill, M., & Greene, W. (2015). Streetscape Features Related to Pedestrian Activity. *Journal of Planning Education and Research*. doi:10.1177/0739456x15591585
Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: urban design qualities related to walkability. *Journal of Urban Design, 14*(1), 65-84.
Ewing, R., Handy, S., Brownson, R. C., Clemente, O., & Winston, E. (2006). Identifying and Measuring Urban Design Qualities Related to Walkability. *Journal of Physical Activity and Health, 3*(1), S223-S240.
Ewing, R., Schieber, R. A., & Zegeer, C. V. (2003). Urban Sprawl as a Risk Factor in Motor Vehicle Occupant and Pedestrian Fatalities. *American journal of public health, 93*(9), 1541-1545. doi:10.2105/AJPH.93.9.1541
Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics* (4th ed.). London: SAGE Publications Ltd.
Frank, L., Bradley, M., Kavage, S., Chapman, J., & Lawton, T. K. (2008). Urban form, travel time, and cost relationships with tour complexity and mode choice. *Transportation, 35*(1), 37-54. doi:10.1007/s11116-007-9136-6
Frank, L., Kavage, S., Greenwald, M., Chapman, J., & Bradley, M. (2009). I-PLACE3S health and climate enhancements and their application in King County'. *Seattle, WA: King County HealthScape*.
Frank, L. D., Sallis, J. F., Conway, T. L., Chapman, J. E., Saelens, B. E., & Bachman, W. (2006). Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality. *Journal of the American Planning Association, 72*(1), 75-87. doi:10.1080/01944360608976725

Freeman, L. C. (1977). A Set of Measures of Centrality Based on Betweenness. *Sociometry, 40*(1), 35-41. doi:10.2307/3033543

Frey, H. (2004). *Designing the City*: Taylor & Francis.

Gans, H. J. (1968). *People and plans*: Basic Books, Incorporated.

Geary, R. C. (1954). The Contiguity Ratio and Statistical Mapping. *The Incorporated Statistician, 5*(3), 115-146. doi:10.2307/2986645

Gehl, J. (1987). *Life Between Buildings: Using Public Space*. New York: Van Nostrand Reinhold.

Ghasemi, A., & Zahediasl, S. (2012). Normality Tests for Statistical Analysis: A Guide for Non-Statisticians. *International Journal of Endocrinology and Metabolism, 10*(2), 486-489. doi:10.5812/ijem.3505

Gibson, J. J. (1966). The Environment as a Source of Stimulation *The senses considered as perceptual systems* (pp. 7-30). Boston: Houghton Mifflin.

Glasgow Centre for Population Health. (2014). Physical Activity. Retrieved from http://www.understandingglasgow.com/indicators/lifestyle/physical_activity

Glasgow City Council. (2013). *Design Guide: New Residential Areas*. Retrieved from Glasgow: www.glasgow.gov.uk/designguideresidential

Google Inc. (2016). Google Street View (Version 203). Mountain View, CA: Google. Retrieved from https://www.google.com/intl/en_ALL/streetview/

Greenwald, M., & Boarnet, M. (2001). Built Environment as Determinant of Walking Behavior: Analyzing Nonwork Pedestrian Travel in Portland, Oregon. *Transportation Research Record: Journal of the Transportation Research Board, 1780*, 33-41. doi:doi:10.3141/1780-05

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate data analysis* (Vol. 6): Pearson Prentice Hall Upper Saddle River, NJ.

Hallgren, K. A. (2012). Computing Inter-Rater Reliability for Observational Data: An Overview and Tutorial. *Tutorials in quantitative methods for psychology, 8*(1), 23-34.

Handy, S. (1993). Regional Versus Local Accessibility: Implications for Nonwork Travel.

Handy, S. (2005). Critical assessment of the literature on the relationships among transportation, land use, and physical activity. *Transportation Research Board and the Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use. Resource paper for TRB Special Report, 282*.

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-Selection in the Relationship between the Built Environment and Walking: Empirical

Evidence from Northern California. *Journal of the American Planning Association, 72*(1), 55-74. doi:10.1080/01944360608976724

Handy, S., & Clifton, K. (2001). Local shopping as a strategy for reducing automobile travel. *Transportation, 28*(4), 317-346. doi:10.1023/A:1011850618753

Harvey, C., & Aultman-Hall, L. (2016). Measuring Urban Streetscapes for Livability: A Review of Approaches. *The Professional Geographer, 68*(1), 149-158. doi:10.1080/00330124.2015.1065546

Heath, G. W., Brownson, R. C., Kruger, J., Miles, R., Powell, K. E., Ramsey, L. T., & Services, T. F. o. C. P. (2006). The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. *Journal of Physical Activity & Health, 3*, S55.

Heath, T., Smith, S. G., & Lim, B. (2000). Tall Buildings and the Urban Skyline: The Effect of Visual Complexity on Preferences. *Environment and Behavior, 32*(4), 541-556. doi:10.1177/00139160021972658

Hedman, R., & Jaszewski, A. (1984). *Fundementals of Urban Design*. Chicago: American Planning Association.

Hoehner, C. M., Ivy, A., Brennan Ramirez, L. K., Handy, S., & Brownson, R. C. (2007). Active neighborhood checklist: a user-friendly and reliable tool for assessing activity friendliness. *American Journal of Health Promotion, 21*(6), 534-537.

Horsey, M. (1990). *Tenements & towers: Glasgow working-class housing 1890-1990*: Royal Commission on the Ancient and Historical Monuments of Scotland Edinburgh.

Howard, E. (1902). Garden cities of tomorrow. *London, itd: Faber and Faber*.

Hussey, D. L. (2010). Nonprobability Sampling. In N. J. Salkind (Ed.), *Encyclopedia of Research Design* (pp. 922-926). Thousand Oaks, CA: SAGE Publications, Inc.

IBM Corp. (2015). IBM SPSS Statistics for Windows. Armonk, NY: IBM Corp.

Irwin, M. (2013). How Glasgow moves. Retrieved from http://open.glasgow.gov.uk/active-travel-intro/

Ittelson, W. H., Rivlin, L. G., Proshansky, H. M., & Winkel, G. H. (1974). *An Introduction to Environmental Psychology*. San Francisco: Holt, Rinehart and Winston, Inc.

Jacobs, A. (1993). *Great Streets*. Cambridge, MA: MIT Press.

Jacobs, A., & Appleyard, D. (1987). Toward an Urban Design Manifesto. *Journal of the American Planning Association, 53*(1), 112-120. doi:10.1080/01944368708976642

Jacobs, J. (1961). The Death and Life of Great American Cities. New York: Random House.

Kline, P. (1999). The handbook of psychological testing routledge: London.
Kockelman, K. (1997). Travel behavior as function of accessibility, land use mixing, and land use balance: evidence from San Francisco Bay Area. *Transportation Research Record: Journal of the Transportation Research Board*(1607), 116-125.
Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics, 33*(1), 159-174. doi:10.2307/2529310
Lang, J. (1987). *Creating Architectural Theory: The Role of the Behavioral Sciences in Environmental Design*. Wokingham: Van Nostrand Reinhold Company Inc.
Le Corbusier. (1929). *The City of To-morrow and Its Planning*. New York: Dover Publications, Inc.,1987 (original 1929).
Le Corbusier. (1933). *La ville radieuse: éléments d'une doctrine d'urbanisme pour l'équipement de la civilisation machiniste*: Vincent, Fréal.
Lee, I.-M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The Lancet, 380*(9838), 219-229. doi:10.1016/s0140-6736(12)61031-9
Lee, R. E., Booth, K. M., Reese-Smith, J. Y., Regan, G., & Howard, H. H. (2005). The Physical Activity Resource Assessment (PARA) instrument: evaluating features, amenities and incivilities of physical activity resources in urban neighborhoods. *International Journal of Behavioral Nutrition and Physical Activity, 2*(1), 13.
Lee, S., & Talen, E. (2014). Measuring Walkability: A Note on Auditing Methods. *Journal of Urban Design, 19*(3), 368-388. doi:10.1080/13574809.2014.890040
Lipman, A. (1974). The Architectural Belief System and Social Behavior. In J. Lan, C. Burnette, W. Moleski, & D. Vachon (Eds.), *Designing for Human Behavior: Architecture and the Behaviorial Sciences* (Vol. 6, pp. 23-30). Stroudsburg, PA: Dowden, Hutchinson & Ross.
Llewelyn Davies Yeang. (2000). *Urban Design Compendium* (1st ed.). London: English Partnerships.
Lockton, D. (2012). *'POSIWD and determinism in design for behaviour change*. Retrieved from http://ssrn.com/abstract=2033231
Long, J. S., & Freese, J. (2006). *Regression Models for Categorical Dependent Variables Using Stata, Second Edition*: Taylor & Francis.
Lynch, K. (1960). *The Image of the City*. Cambridge, MA: MIT Press.
Marmot, A. (2002). Architectural determinism. Does design change behaviour? *The British Journal of General Practice, 52*(476), 252-253.

Marquardt, D. W. (1970). Generalized Inverses, Ridge Regression, Biased Linear Estimation, and Nonlinear Estimation. *Technometrics, 12*(3), 591-612. doi:10.2307/1267205

Maxwell, J. A., & Wolfe, C. R. (2014). City main street networks show a drastic shift away from historic patterns of human-scale design. Retrieved from http://bit.ly/1j2IBDb

McMillan, T. E. (2005). Urban Form and a Child's Trip to School: The Current Literature and a Framework for Future Research. *Journal of Planning Literature, 19*(4), 440-456. doi:10.1177/0885412204274173

McMillan, T. E. (2007). The relative influence of urban form on a child's travel mode to school. *Transportation Research Part A: Policy and Practice, 41*(1), 69-79.

Menard, S. (1995). Applied logistic regression analysis: Sage university series on quantitative applications in the social sciences: Thousand Oaks, CA: Sage.

Microsoft. (2016). Bing Maps. Redmond, Washington: Microsoft Corporation.

Millington, C., Ward Thompson, C., Rowe, D., Aspinall, P., Fitzsimons, C., Nelson, N., & Mutrie, N. (2009). Development of the Scottish Walkability Assessment Tool (SWAT). *Health & Place, 15*(2), 474-481. doi:http://dx.doi.org/10.1016/j.healthplace.2008.09.007

Millstein, R. A., Cain, K. L., Sallis, J. F., Conway, T. L., Geremia, C., Frank, L. D., . . . Saelens, B. E. (2013). Development, scoring, and reliability of the Microscale Audit of Pedestrian Streetscapes (MAPS). *BMC Public Health, 13*(1), 1-15. doi:10.1186/1471-2458-13-403

Mitchell, R. (2013). Is physical activity in natural environments better for mental health than physical activity in other environments? *Social Science & Medicine, 91*, 130-134. doi:http://dx.doi.org/10.1016/j.socscimed.2012.04.012

Moran, P. A. P. (1950). Notes on Continuous Stochastic Phenomena. *Biometrika, 37*(1/2), 17-23. doi:10.2307/2332142

Moudon, A. V. (1992). A Catholic Approach to Organizing What Urban Designers Should Know. *Journal of Planning Literature, 6*(4), 331-349. doi:10.1177/088541229200600401

Moudon, A. V., & Lee, C. (2003). Walking and bicycling: an evaluation of environmental audit instruments. *American Journal of Health Promotion, 18*(1), 21-37.

Nasar, J. L. (1987). The Effect of Sign Complexity and Coherence on the Perceived Quality of Retail Scenes. *Journal of the American Planning Association, 53*(4), 499-509. doi:10.1080/01944368708977139

National Health Service Greater Glasgow and Clyde. (2006). *Let's make Glasgow more active: A physical activity strategy for Glasgow 2007-2012*. Retrieved from Glasgow:

National Records of Scotland. (2014). *Glasgow City Council Area - Demographic Factsheet*. Retrieved from http://www.nrscotland.gov.uk/files/statistics/council-area-data-sheets/glasgow-city-factsheet.pdf

Neckerman, K. M., Purciel-Hill, M., Quinn, J. W., & Rundle, A. (2013). Urban Design Qualities for New York City. In R. Ewing & O. Clemente (Eds.), *Measuring Urban Design: Metrics for Livable Places* (pp. 63-82). London: Island Press.

Nelessen, A. C. (1994). *Visions for a New American Dream: Process, Principles, and an Ordinance to Plan and Design Small Communities* (2nd ed.). Chicago: American Planning Association.

Odgers, C. L., Caspi, A., Bates, C. J., Sampson, R. J., & Moffitt, T. E. (2012). Systematic social observation of children's neighborhoods using Google Street View: a reliable and cost-effective method. *Journal of Child Psychology and Psychiatry, 53*(10), 1009-1017. doi:10.1111/j.1469-7610.2012.02565.x

Office for National Statistics. (2014). *Mid-2013 Population Estimates: Population density of the United Kingdom; estimated resident population.*

Office for National Statistics. (2015). *MYE2: Population Estimates by single year of age and sex for local authorities in the UK, mid-2013*. Retrieved from: http://www.ons.gov.uk/ons/rel/pop-estimate/population-estimates-for-uk--england-and-wales--scotland-and-northern-ireland/2013/index.html

Ozbil, A., Peponis, J., & Stone, B. (2011). Understanding the link between street connectivity, land use and pedestrian flows. *Urban Design International, 16*(2), 125-141.

Perry, C. (1929). *Regional Survey of New York and Its Environs*. Retrieved from New York:

Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K., & Donovan, R. (2003). Developing a framework for assessment of the environmental determinants of walking and cycling. *Social Science & Medicine, 56*(8), 1693-1703. doi:http://dx.doi.org/10.1016/S0277-9536(02)00163-6

Pikora, T. J., Bull, F. C. L., Jamrozik, K., Knuiman, M., Giles-Corti, B., & Donovan, R. J. (2002). Developing a reliable audit instrument to measure the physical environment for physical activity. *American Journal of Preventive Medicine, 23*(3), 187-194. doi:http://dx.doi.org/10.1016/S0749-3797(02)00498-1

Pikora, T. J., Giles-Corti, B., Knuiman, M. W., Bull, F. C., Jamrozik, K., & Donovan, R. J. (2006). Neighborhood environmental factors correlated with walking near home: Using SPACES. *Medicine and science in sports and exercise, 38*(4), 708-714. doi:10.1249/01.mss.0000210189.64458.f3

Placemeter Inc. (2016). Quantify the Wold: Placemeter Measures the Pulse of Cities Worldwide. Retrieved from https://www.placemeter.com/

Pont, K., Ziviani, J., Wadley, D., Bennett, S., & Abbott, R. (2009). Environmental correlates of children's active transportation: A systematic literature review. *Health & Place, 15*(3), 849-862. doi:http://dx.doi.org/10.1016/j.healthplace.2009.02.002

Porta, S., Crucitti, P., & Latora, V. (2006a). The network analysis of urban streets: a dual approach. *Physica A: Statistical Mechanics and its Applications, 369*(2), 853-866.

Porta, S., Crucitti, P., & Latora, V. (2006b). The network analysis of urban streets: a primal approach. *ENVIRONMENT AND PLANNING B PLANNING AND DESIGN, 33*(5), 705.

Porta, S., Crucitti, P., & Latora, V. (2008). Multiple centrality assessment in Parma: a network analysis of paths and open spaces. *Urban Design International, 13*(1), 41-50.

Porta, S., Latora, V., Wang, F., Strano, E., Cardillo, A., Scellato, S., . . . Messora, R. (2008). Street centrality and densities of retail and services in Bologna, Italy. *Environment and Planning B: Planning and design, 36*(3), 450-465.

Porta, S., Romice, O., Maxwell, J. A., Russell, P., & Baird, D. (2014). Alterations in scale: Patterns of change in main street networks across time and space. *Urban Studies, 51*(16), 3383-3400. doi:10.1177/0042098013519833

Porteous, J. D. (1977). *Environment & behavior: planning and everyday urban life*: Addison-Wesley Reading, Mass.

Prince, H. C. (1971). Real, imagined and abstract worlds of the past. *Progress in Geography, 3*(s I), 36.

Putney, L. G. (2010). Case Study. In N. J. Salkind (Ed.), *Encyclopedia of Research Design* (pp. 116-120). Thousand Oaks, CA: SAGE Publications, Inc.

Rapoport, A. (1990). *History and Precedent in Environmental Design*: Springer US.

Rapoport, A., & Hawkes, R. (1970). The Perception Of Urban Complexity. *Journal of the American Institute of Planners, 36*(2), 106-111. doi:10.1080/01944367008977291

Rapoport, A., & Kantor, R. E. (1967). Complexity and Ambiguity in Environmental Design. *Journal of the American Institute of Planners, 33*(4), 210-221. doi:10.1080/01944366708977922

Ratti, C. (2004). Space syntax: some inconsistencies. *Environment and Planning B: Planning and design, 31*(4), 487-499.

Redström, J. (2006). Persuasive design: Fringes and foundations *Persuasive Technology* (pp. 112-122): Springer.

Reed, P. (1999). *Glasgow : The Forming of the City*. Edinburgh: Edinburgh University Press.

Reid, M. (2011). *Behind the "Glasgow effect"*. Retrieved from http://www.who.int/bulletin/volumes/89/10/11-021011/en/

Riddell, R. (2014). Get walking in the city. Retrieved from http://open.glasgow.gov.uk/walkonomics/

Rodrıguez, D. A., & Joo, J. (2004). The relationship between non-motorized mode choice and the local physical environment. *Transportation Research Part D: Transport and Environment, 9*(2), 151-173. doi:http://dx.doi.org/10.1016/j.trd.2003.11.001

Royston, J. P. (1982). An Extension of Shapiro and Wilk's W Test for Normality to Large Samples. *Journal of the Royal Statistical Society. Series C (Applied Statistics), 31*(2), 115-124. doi:10.2307/2347973

Royston, P. (1992). Approximating the Shapiro-Wilk W-test for non-normality. *Statistics and Computing, 2*(3), 117-119. doi:10.1007/bf01891203

Rundle, A. G., Bader, M. D. M., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to Audit Neighborhood Environments. *American Journal of Preventive Medicine, 40*(1), 94-100. doi:http://dx.doi.org/10.1016/j.amepre.2010.09.034

Saelens, B. E., & Handy, S. L. (2008). Built Environment Correlates of Walking: A Review. *Medicine and science in sports and exercise, 40*(7 Suppl), S550-S566. doi:10.1249/MSS.0b013e31817c67a4

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of behavioral medicine, 25*(2), 80-91.

Salheen, M., & Forsyth, L. (2001). Addressing distance in the space syntax syntactical model. *Urban Design International, 6*(2), 93-110.

Scarborough, P., Bhatnagar, P., Wickramasinghe, K. K., Allender, S., Foster, C., & Rayner, M. (2011). The economic burden of ill health due to diet, physical inactivity, smoking, alcohol and obesity in the UK: an update to 2006-07 NHS costs. *J Public Health (Oxf), 33*(4), 527-535. doi:10.1093/pubmed/fdr033

Scottish Council of Economic Advisers. (2008). *First Annual Report of the Scottish Council of Economic Advisers: December 2008*. Retrieved from

Scottish Government. (2010). *Designing Streets: A Policy Statement for Scotland*. (978-0-7559-8264-6). Edinburgh: RR Donnelley.

Scottish Government. (2011). *Designing Places: A Policy Statement for Scotland*. (0 7559 0037 5). Edinburgh: Scottish Government.

Scottish Government. (2015). *Local governement area boundaries in Scotland: 1995 onwards*. Retrieved from Edinburgh: http://www.lgbc-scotland.gov.uk/publications/information_papers/

Sevtsuk, A. (2010). *Path and Place: A Study of Urban Geometry and Retail Activity in Cambridge and Somerville, MA.* (PhD City Planning), Massachusetts Institute of Technology, Cambridge, Mass.

Shapiro, S. S., & Wilk, M. B. (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika, 52*(3/4), 591-611. doi:10.2307/2333709

Shriver, K. (2003). *A walkable places survey: Approach and results.* Paper presented at the Transportation Research Board Annual Meeting, Washington DC, Paper.

Sitte, C. (1889). *City Planning According to Artistic Principles*. Public domain.

Sitte, C. (1979). *The art of building cities : city building according to its artistic fundamentals* (Hyperion reprint ed. ed.). Westport, Conn.: Westport, Conn. : Hyperion Press.

Stamps, A. E. (1998). Measures of architectural mass: from vague impressions to definite design features. *Environment and Planning B, 25*, 825-836.

Stamps, A. E. (1999). Physical Determinants of Preferences for Residential Facades. *Environment and Behavior, 31*(6), 723-751. doi:10.1177/00139169921972326

Stamps, A. E. (2005). Enclosure and Safety in Urbanscapes. *Environment and Behavior, 37*(1), 102-133. doi:10.1177/0013916504266806

Stamps, A. E., Nasar, J. L., & Hanyu, K. (2005). Using Pre-construction Validation to Regulate Urban Skylines. *Journal of the American Planning Association, 71*(1), 73-91. doi:10.1080/01944360508976406

Stamps, A. E., & Smith, S. (2002). Environmental Enclosure in Urban Settings. *Environment and Behavior, 34*(6), 781-794. doi:10.1177/001391602237246

Stead, D., & Marshall, S. (2001). The relationships between urban form and travel patterns. An international review and evaluation. *European Journal of Transport and Infrastructure Research, 1*(2), 113-141.

Targa, F., & Clifton, K. J. (2005). The built environment and trip generation for non-motorized travel. *Journal of Transportation and Statistics, 8*(3), 55-70.

Trochim, W. M. K. (2006, 10/20/2006). Nonprobability Sampleing. *The Research Methods Knowledge Base*. 2nd. Retrieved from http://www.socialresearchmethods.net/kb/sampnon.php
Tunnard, C., & Pushkarev, B. (1963). *Man-Made America: Chaos or control?* New Haven: Yale University Press.
U.S. Department of Transportation Federal Highway Administration. (n.d.). Natioanl Household Travel Survey.   Retrieved from http://nhts.ornl.gov/index.shtml
UCLA: Statistical Consulting Group. (2016). SPSS Data Analysis Examples: Negative Binomial Regression.   Retrieved from http://www.ats.ucla.edu/stat/spss/dae/neg_binom.htm
UDSU. (2015). Urban Design Studies Unit (UDSU).   Retrieved from http://www.udsu-strath.com/
United Nations Human Settlements Programme. (2013). *Streets As Public Spaces and Drivers of Urban Prosperity*. Retrieved from
Code of Practice on Investigations Involving Human Beings, (2013a).
University of Strathclyde. (2013b). Guidance on Completing the Ethics Form (pp. 8). University of Strathclyde: University of Strathclyde, University Ethics Committee.
Unwin, R. (1909). *Town Planning in Practice: An Introduction to the Art of Designing Cities and Suburbs*: T. F. Unwin.
Victoria Transport Policy Institute. (2016). Streetscape Improvements: Enhancing Urban Roadway Design. *TDM Encyclopedia*. Retrieved from http://www.vtpi.org/tdm/tdm122.htm
Vittinghoff, E., Shiboski, S. C., Glidden, D. V., & McCulloch, C. E. (2005). Generalized Linear Models *Regression Methods in Biostatistics: Linear, Logistic, Survival, and Repeated Measures Models* (pp. 291-303). New York, NY: Springer New York.
Walk Score. (2016). Walk Score.   Retrieved from https://www.walkscore.com/
Wang, F., Antipova, A., & Porta, S. (2011). Street centrality and land use intensity in Baton Rouge, Louisiana. *Journal of Transport Geography, 19*(2), 285-293. doi:http://dx.doi.org/10.1016/j.jtrangeo.2010.01.004
Westfall, P. H. (2014). Kurtosis as peakedness, 1905–2014. rip. *The American Statistician, 68*(3), 191-195.
WHO. (2010). *Global recommendations on physical activity for health*: World Health Organization.
WHO. (2014, February 2014). Physical activity. Fact sheet #385. Retrieved from http://www.who.int/mediacentre/factsheets/fs385/en/#
Whyte, W. H. (1980). *The Social Life of Small Urban Spaces*. New York: The Project for Public Spaces.

Whyte, W. H. (1988). *City: Rediscovering the Center*. New York: Anchor.
Wilson, J. S., Kelly, C. M., Schootman, M., Baker, E. A., Banerjee, A., Clennin, M., & Miller, D. K. (2012). Assessing the Built Environment Using Omnidirectional Imagery. *American Journal of Preventive Medicine, 42*(2), 193-199. doi:http://dx.doi.org/10.1016/j.amepre.2011.09.029
Zhang, M. (2004). The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. *Journal of the American Planning Association, 70*(3), 344-360. doi:10.1080/01944360408976383

APPENDICES

Appendix A Glasgow's Diversity of Architecture and Urban Design

Tenement building, Hillhead (Source: © User: dshaw/Wikimedia Commons/CC-BY-SA-3.0)

Pedestrianized shopping area, City Centre (Source: © Finlay McWalter/Wikimedia Commons/CC-BY-SA-3.0)

Office buildings in International Financial Services District, St Vincent Place (Source: © Barbara Carr/Geograph/CC-BY-SA-2.0)

Multi-story warehouse, Jamaica Street (Source: © Chris Allen/Geograph/CC-BY-SA-2.0)

Living above shops, Great Western Road (Source: © Thomas Nugent/Geograph/CC-BY-SA-2.0)

Gleneagles cottages, Scoutstoun (Source: © Barbara Carr/Geograph/CC-BY-SA-2.0)

Terraced row houses, Hyndland (Source: © Chris Upson/Wikimedia Commons/CC-BY-SA-2.0)

Industrial building, Elliot Street (Source: © Thomas Nugent/Geograph/CC-BY-SA-2.0)

Semi-detached suburban housing, Knightswood (Source: © M J Richardson/Geograph/CC-BY-SA-2.0)

Forge retail park (Source: © Stephen Sweeney/Geograph/CC-BY-SA-2.0)

Cranhill tower blocks (Source: © Chris Upson/Geograph/CC-BY-SA-2.0)

High Street (Source: © Kim Traynor/Wikimedia Commons/CC-BY-SA-3.0)

Newer housing development in Glasgow Harbour (Source: © Thomas Nugent/Geograph/CC-BY-SA-2.0)

Newer housing development, Ardencraig Road (Source: © Stephen Sweeney /Geograph/CC-BY-SA-2.0)

Glasgow School of Art (Source: © Chris Downer/Geograph/CC-BY-SA-2.0)

BBC Building and Science Centre (Source: © Thomas Nugent/Geograph/CC-BY-SA-2.0)

Riverside Museum (Source: © Gordon Hatton/Geograph/CC-BY-SA-2.0)

Glasgow City Chambers and George Square (Source: © Andy Farrington/Geograph/CC-BY-SA-2.0)

People's Palace and Winter Gardens, Glasgow Green (Source: © Kim Traynor/Geograph/CC-BY-SA-2.0)

Glasgow Cathedral (Source: © Mary and Agnus Hogg/Geograph/CC-BY-SA-2.0)

Appendix B Short Biographies of Local Experts

Name	Biography
Mr Gordon Barbour	Gordon is a qualified Glasgow-based architect with over 25 years of experience. He studied architecture at both the University of Edinburgh and the Oxford Polytechnic. After working in private practice, he transitioned into the public sector, working on social housing. He has worked for Scottish Homes, the National Housing Agency, Glasgow City Council, and is currently serving as the development manager for the Glasgow Housing Association. As a researcher, his research focuses on urban regeneration and housing within Glasgow.
Ms Paola Pasino	Paola is a qualified architect based in Glasgow, currently working with the Glasgow City Council as a project manager. Her work within the public sector focuses on housing, development and regeneration services, with a recent emphasis on city center regeneration. As a researcher, she also studies the relationship between urban morphology and social deprivation within the City of Glasgow.
Dr Ombretta Romice	Ombretta is a senior lecturer at the University of Strathclyde and past president of the International Association for People Environment Studies. She teaches and conducts research in the areas of urban design, environmental behavior studies, urban morphology and user participation. She holds a PhD in urban design and post doc in housing and regeneration.
Prof Sergio Porta	Sergio is a professor of urban design and the director of the Urban Design Studies Unit at the University of Strathclyde. He served as former head of the Department of Architecture at the University of Strathclyde from 2011-2014. His research expertise includes urban morphology, street network analysis, and urban design.

Appendix C Video Recording Protocol

Materials list

- GoPro Hero 3+ camera, 2 spare batteries, and housing
- Helmet (with GoPro mount)
- USB cable
- 32GB SD memory card

Getting started (before entering the field)

Assemble camera

1. Insert SD memory card into the SD card slot located on the side of the GoPro Hero 3+ camera.
2. Install the battery into back of the camera.
3. Power on the camera by pressing and releasing the power button located on the front of the camera. The LED recording light on the front of the camera will flash three times to indicate that the camera is on.
4. Check that the battery is fully charged, indicated by the battery meter on the LCD status screen, located on the front of the camera.
5. (If not fully charged) Charge battery by connecting the USB cable to the USB port located on the side of the camera to a USB power supply.

Assemble camera, housing and mount

1. Attach the camera housing to the helmet using thumb screw.
2. Twist thumb screw until housing is securely mounted to the helmet.
3. Assembling the camera
4. Place the camera into housing.
5. Close the housing door and hook latch under groove on the backdoor.

6. Push down the thumb latch until the housing locks into place.

Verify camera mode and settings

1. Verify the camera is in video mode, indicated by the video icon on the LCD.
2. (If not in video mode) Press the power button repeatedly until the video icon is displayed.
3. Verify the camera is set to the following setting, indicated by the icons on the LCD:
   - Video resolution/Frames per second (FPS): 1080p-60
   - Field of view (FOV): 170° Wide

(If not adjusted to proper settings) Adjust camera settings

1. Press the power button repeatedly until the LCD displays the settings icon.
2. Press the shutter button on the top of the camera to select the settings menu.
3. (To adjust video resolution/FPS) Press the power button repeatedly until the LCD displays the icon for the video resolution mode. Press the shutter button to select video resolution mode. Press the power button repeatedly to toggle through the list of settings until LCD displays 1080-60. Press the shutter button to select the highlighted resolution setting and exit the resolution settings list.
4. (To adjust FOV) Press the power button repeatedly until the LCD displays the icon for the FOV mode. Press the shutter button to select FOV mode. Press the power button repeatedly to toggle through the list of settings until LCD displays 170°. Press the shutter button to select the highlighted FOV setting and exit the resolution settings list.

5. From the exit screen, press the power button to return to the camera's normal camera mode.

Recording streetscape videos (in the field)

1. Mount camera to helmet.
2. To record a video, press and release the shutter button. The LED recording light will flash continuously while recording.
3. Proceed as follows:
    a. Start approximately 5 meters (m) from the beginning of the block on the outside of the pavement
    b. Walk forward in the direction of adjacent traffic at an approximate speed of 1 mile per hour (mph)
    c. While walking, looking straight ahead, keeping your head level until you have reached the end of the block or boundary of the study area
    d. Briefly pan left, then pan right, and then stop recording by pressing and releasing the shutter button. The LED recording light will flash three times to indicate that the camera is no longer recording
    e. Turn around and repeat steps a-d for a total of 4 times – these will be samples 1-4 (the walk-through clips)
    f. At the end of the fourth walk-through stop the recording and walk midway up the sample street segment
    g. At approximately the midpoint of the sample street segment, turn to face the opposite side of street, keeping your head level
    h. Record a brief 3-5 second video, pressing and releasing the shutter button to start and stop the camera – this will be sample 5 (view across clip)

i. Cross the street to the opposite side of the sample street segment, and starting at one end of the street segment, record a video of the entire length of the street segment while keeping your head level and your head turned 30°-45° away from the street towards the adjacent plots – this will be sample 6 (opposite side)
j. Cross the street again to the original side of the sample street segment and repeat the process for step i (above) – this will be sample 7 (your side)
k. Once all 7 sample clips have been collected, sampling for that sample street segment is complete
l. Turn the camera off to conserve battery

Uploading, editing, and storing video clips (in the office)

Transferring video files to computer

1. Remove camera from housing.
2. Connect camera to computer using USB cable.
3. Press the power button to turn the camera on.
4. Locate the camera as a removable disk on the computer and open the DCIM folder.
5. Open the 100GOPRO folder and select videos to copy and paste to computer hard drive.

Editing

1. Save all seven clips in a sample folder with the number of the sample street segment (e.g., "0359")
2. Label each clip according to the samples street segment number and number of the clip (e.g., "0359_01" to indicate Clip 1 (walk-through 1) from sample street segment 359)

Storing samples

1. Store copies of all sample clips in at least two different locations (e.g., physical hard drive and a remote server) before formatting the SD card in the camera

Draft 2014

Measuring Urban Design Qualities Related to Walkability in the Pedestrian Streets of Glasgow, United Kingdom (UK): Field Manual

Prepared by:

J. Alexander Maxwell | *Research coordinator, PhD Candidate*

Urban Design Studies Unit, Department of Architecture, University of Strathclyde

Alisson Pazetto, Cíntia Brito, Joseane Ruivo and Luisa Gusmão | *Research assistants*

Department of Architecture, University of Strathclyde

In consultation with:

Professor Reid Ewing

Department of City & Metropolitan Planning, University of Utah

1 Table of Contents

2 Introduction

Streets are one of the most important and more permanent elements of the public realm (A. B. Jacobs, 1993). Streets not only provide a link between daily amenities, but also a context for public life and physical activity(A. B. Jacobs, 1993; J. Jacobs, 1961). Urban designers, health researchers, non-governmental organizations and government agencies at various scales have placed an increasing priority on the quality of urban environments over the past several years as a way to promote healthier and more sustainable urban environments. This priority is reflected in several recent publications both here in Scotland but also throughout the rest of the UK and indeed around the world (CIHT, 2010; Department for Transport, 2007; Design Council, 2014; Scottish Government, 2010; UN-Habitat, 2013).

One of the most important measures of the overall quality of urban environments is walkability – the measure of how conducive an area is to walking and other pedestrian activities[1]. Though many factors may influence walkability (e.g., street connectivity, population density, weather, etc.), perceptual qualities of urban design (e.g., enclosure, human scale, and tidiness) are believed to play an important, intermediary role in promoting pedestrian activity (Figure 1).

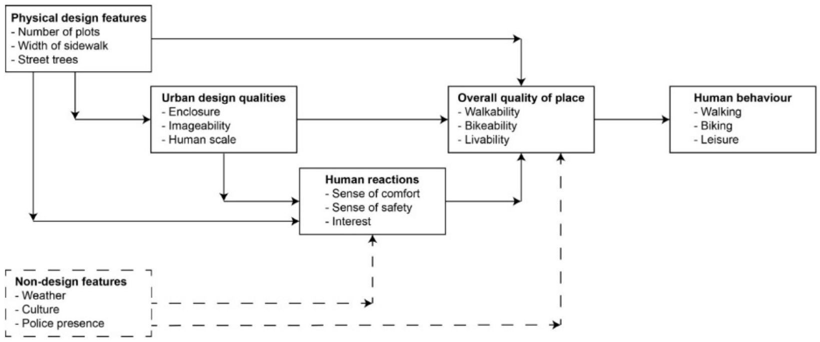


Figure 1 – Conceptual framework for the study adapted from Figure 1 in Ewing and Clemente (2013, p. 67)

The measures used in many previous studies characterizing the built environment in relation to walkability and physical activity tend to focus on gross measures of urban form (e.g., street connectivity and density) (Ewing, 2005; Ewing & Cervero, 2010; Handy, 2005) and green or recreational spaces designed for physical activity (Coombes, Jones, & Hillsdon, 2010; Hillsdon, Panter, Foster, & Jones, 2006; Lindsey, Han, Wilson, & Yang, 2006; Tilt, Unfried, & Roca, 2007). What these studies often fail to capture are the subtle, perceptual urban design qualities observed by pedestrians (often unknowingly) while walking streets that are believed to help promote physical activity(Ewing & Handy, 2009). However, empirical evidence to support this idea

[1] Technical disciplines (e.g., transportation engineering, urban planning, and public health) concerned with walking often define walkability in nuanced ways according to their respective terminologies. However, for the purposes of this study, the definition of walkability provided above, adapted from Abley (2005), is in agreement with the its usage in previous studies of this nature, including Ewing and Clemente (2013). For more on the etymology of the term, walkability, see Chapter 2 of Abley (2005).

through validated, objective measures of urban design qualities in large-scale, city-wide studies remains limited(Neckermann, Purciel-Hill, Quinn, & Rundle, 2013).

2.1 About this manual

Urban design literature is replete with references to different perceptual qualities, linking public spaces like streets to health, environmental, social, and other outcomes. However, objectively defining many of these qualities and operationalizing them through reliable measures is often difficult. The urban design qualities and their related features in this manual are ones that have recently been shown in previous studies (Ewing & Clemente, 2013; Ewing & Handy, 2009) to not only have a significant relationship to walkability but also a high potential to be measured objectively and reliably.

Note on previous manuals

This field manual was developed over the course of the summer of 2014 to measure the urban design qualities of central, pedestrian streets in Glasgow, UK. This manual is an adaptation of previous manuals developed by Professor Reid Ewing and his colleagues in previous studies conducted in the United States (Clemente, Ewing, Handy, & Brownson, 2005; Ewing & Clemente, 2013; Purciel & Marrone, 2006). While many of the definitions and steps are taken verbatim from these previously developed manuals, several adaptations were made to the language, examples, and phrasing used to allow for easier application and understanding within the context of the UK, particularly in City of Glasgow. Additionally, several of the adaptations seek to clarify several steps in the previous manual that remained confusing.

Structure of the manual

This manual will provide a qualitative introduction to each of the measurable urban design qualities and then provide guidance on how to objectively measure each quality based on an index of observable features that can be empirically measured while walking along the sample street segments. The urban design qualities operationalized in this manual are: imageability, enclosure, human scale, transparency and complexity.

2.2 Field equipment and materials

- Copy of the manual
- Copy (or copies) of the scoring sheet (see appendix)
- Map of the study area including sample street segment locations
- Clipboard
- Several pens or pencils
- Additional notepad
- Water, sunscreen, sunglasses, umbrella, and comfortable walking shoes
- Mobile phone with emergency contacts

2.3 Study area

Identify the street segment for auditing according to the table of metadata provided (Table 1).

Table 1 – Sample table of metadata used to identify sample street segments

Sample ID	DZ_CODE	FID_MCA_GL	Betweenness	Seg_length	Street	Cross street (from)	Cross street (to)	Side of street	Approximate address
1	S01003568	59216	0.004596299	58.52902629	Cleveden Rd	Cleveden Dr	Lancaster Cresent Ln	East	8 Cleveden Rd
4	S01003526	82122	0.038853322	93.3033919	Great Western Rd	Hillhead St	Cecil St	South	665 Great Western Rd
5	S01003521	82122	0.038853322	134.5448549	Great Western Rd	Buckingham St	Queen Margaret Dr	South	711 Great Western Rd
6	S01003484	57501	0.00934684	85.89771338	Byres Rd	Havelock St	Highburgh Rd	West	130 Byres Rd

Note the side of the street to be observed based on orientation and the related starting and end points (usually cross streets of the block). The side of the street being observed is known as “your side” with the other side of the street is known as “opposite side”. Observers conducting field audits are only to walk the length of the street segment along the side of the street deemed “your side” while making measurements.

The instructions in this manual require audits of physical features located both “within” and “beyond [the] study area” and on “your side,” the “opposite side,” and “both sides” of the street (included the plots set back no more than 3m from the pavement edge) (Figure 2). Consider “within study area” to be anything within the area of the sample street segment walked or anything that is no more than 15m ahead of the area walked. Consider “beyond study area” to be anything that is no more than 45m from the area walked.

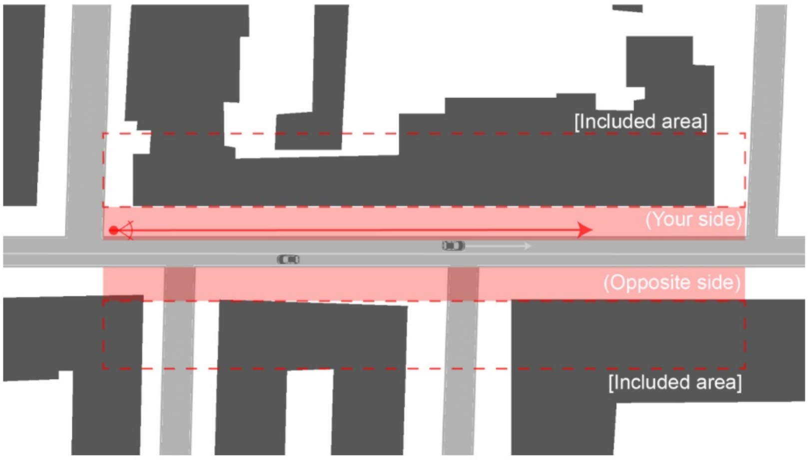


Figure 2 – Example study area indicating the sides of the street, included areas, and direction of travel.

2.4 General definitions

“Fronting the street” – is a phrase used to describe the included area of plots that are set back no more than 3m from the edge of the pavement

“Street level” – is a phrase used to describe the pedestrian level, visible and directly accessible from the street. It extends from the pavement or ground-level to a height of about 3 meters.

Proportion – the percentage that element represents of the entire length of the street frontage.

2.5 Urban design quality definitions and descriptions

Definition: Imageability is the quality of a place that makes it distinct, recognizable, and memorable.

Description: Imageable streets occur when specific physical features and their arrangement complement one another, capture attention, evoke feelings, and create a lasting impression. Architecture that suggests importance, presence of historical buildings, and landmarks are some of the physical features that contribute to imageability.

Definition: Enclosure is the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements.

Description: Enclosed streets have a room like quality, where the height of vertical elements is proportionally related to the width of the space between them. Buildings are the "walls" of the outdoor room, while the street and pavement are the "floor."

Definition: Human scale is the size, texture, and articulation of physical elements that match the size and proportions of humans and correspond to the speed at which humans walk and observe their surroundings.

Description: Human scale streets are characterized by physical features that including architectural and structural components of buildings and pedestrian street furniture.

Definition: Transparency is the degree to which people can see or perceive human activity or what lies beyond the edge of a street.

Description: Transparent streets allow pedestrians to observe human activity, or signs thereof, beyond the street edge.

Definition: Complexity is the visual richness of a place that depends on the variety of the physical environment, including the numbers and kinds of buildings, architectural diversity and ornamentation, street furniture, and human activity.

Description: Complex streets have varied building shapes, sizes, materials, colours, architecture, ornamentation, and setbacks. They also may have many windows and doors, varied lighting, and are usually highly populated.

3 Measurement instructions

3.1 Imageability

The quality of a place that makes it distinct, recognizable, and memorable.

Step 1: Count courtyards, plazas, and parks

Both sides , within study area

Directions:

Count and record the number of (not elements or sections of) individual courtyards, plazas, and parks on both sides of the street with the study area.

Definitions:

- **Courtyard** – is a permanent space that people are intended and able to enter.
- **Plaza** – is a large, enterable open space larger than 2 square metres (m^2), often with objects of public art and plants or associated with buildings.
- **Park** – is a place intended for human use and recreation, often with greenery, a playground, etc.

Note: All counted features must be accessible (i.e., must be designed to be enterable from the pavement by people), either privately or publically. Features behind locked or gated spaces that are not enterable do not count. Large parks that occupy the whole block still count as one park, and left over green spaces that are not intended for use must be excluded from the count.

Examples:

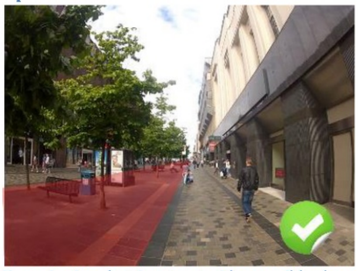


Figure 3 – A pedestrian street with accessible plazas running the length of the street (Location: Sauchiehall St 55°51'53.9"N 4°15'33.3"W)

Figure 4 – A pedestrian plaza associated with two buildings (Location: High St. 55°51'26.4"N 4°14'34.8"W)

Figure 5 – A gated square that is not enterable and therefore does not count (Location: Blythwood Sq. 55°51'49.9"N 4°15'46.3"W)

Figure 6 – A public park accessible at several points along the street (Location: Montrose St. 55°51'43.4"N 4°14'42.3"W)

Frequently asked questions:

Q. Do manicured median strips count?

A. No, median strips, even those with seating, do not count.

Step 2: Count major landscape features

Both sides, beyond study area

Directions:

Count and record the number of distinct, major landscape features observed on both sides of the street and ahead in the distance (visible and prominent features only).

Definitions:

- **Major landscape features** – are prominent natural landscape elements (e.g., bodies of water, mountain ranges, or human-made features that incorporate the natural environment) that serve as natural landmarks for orientation or reference.

Note: Parks do not count as major landscape features.

Examples

Figure 7 – A prominent park ahead in the distance that does not count as a major landscape feature (Location: Circus Dr. 55°51’43.5”N 4°13’34.5”W).

Figure 8 – A body of water, the River Clyde (Location: The Clyde Arc 55°51’26.8”N 4°16’55.5”W).

Figure 9 – A mountain range ahead in the distance that is not prominent enough to be considered a major landscape feature (Location: N. Portland Street, 55°51'43.8"N 4°14'35.9"W).

Figure 10 – Surrounding hills ahead in the distance count are prominent as a major landscape feature (Location: Balmore Rd, 55°54'42.1"N 4°16'09.6"W).

Frequently asked questions:

Q. Does the skyline count?

A. A skyline, though a natural feature, does not count as a natural landscape feature. Skylines are accounted for later in the manual in Enclosure, Steps 3A and 3B.

Q. If a major landscape feature is present but is not observable from the street level, does it still count?

A. No, if the feature is not visible from the street level while walking the length of the sample street segment, it does not count as a major landscape features.

Step 3: Estimate the proportion of historic buildings

Both sides, within study area

Directions:

Estimate and record the proportion of historic buildings visible from the street level within the study area. The proportion is a function of the total length of the sample street segment (excluding cross streets), recorded as a decimal to the nearest tenth (0.10).

Definitions:

- **Historic buildings** – are buildings determined to be constructed prior to World War II (WW II), usually with a high level of detailing, older building materials (e.g., sandstone), etc. By comparison, post-WW II buildings are usually geometrically and architecturally simple (though sometimes impressive) and have more glass surface area and little detailing.

Examples

Figure 11 – The left side of the street is entirely fronted and occupied by historic buildings. The right side of the street is fronted and occupied by approximately 80 per cent historic buildings and 20 per cent modern glass and concrete buildings. This street has approximately 90 per cent of its building frontage (on both sides) occupied by historic buildings. (Location: Bell St. 55°51’29.6”N 4°14’44.8”W)

Frequently asked questions:

Q. What if the building has more than one construction date?

A. The primarily concern is what can be observed at the street level – i.e., the ground level (pedestrian level), including what is visible and directly accessible from the pavement to a height of about 3m. If there is more than one construction date for the street level section of the building and historic elements are still visible, then consider the building historic.

Q. What if it is not clear whether the building is historic?

A. If there is no clear indicator that the building is historic, then it cannot be counted as such.

Step 4: Count buildings with identifiers

Both sides, within study area

Directions

Count and record the number of buildings with identifying features visible from the pavement on both sides of the street within the study area.

Definitions

Identifiers – are clear signs or universal symbols that reveal a building’s street-level use. For example, a steeple can identify a church or cathedral, a gas pump can identify a petrol station, tables and chairs can identify a restaurant, mannequins can identify a clothing store, etc. Words can also identify a plot or building (e.g., primary school, pharmacy, café, or brand/franchise names). A name such as “Al’s” would not be considered as an identifier; however, “Al’s pub” would be considered an identifier.

Note: If a single building has multiple street-level occupants, it is identifiable only if the majority of occupants are identifiable.

Examples

Figure 12 – A building with identifying features. While a name such "One O One" would not count as an identifier, the description below , "Convenience Store", signals the building's street-level use and is therefore an identifier (Location: 55°51'29.2"N 4°14'42.3"W).

Figure 13 – A building with identifying features. Mannequins in the street-level display and the brand name, "Primark", count as identifiers. (Location: Queen St. 55°51'29.0"N 4°15'09.2"W)

Frequently asked questions

Q. Are residential buildings identifiable?

A. Unless there is a visible sign or symbol that clearly identifies the residence (note: doormen do not signify residences), the building is unidentifiable. Flats, manors, condos, tenements, etc. are all words that if present on a sign related to the building signify residential use and can thus be used as identifiers.

Note: Many buildings have been converted and appearance is not reliable.

Q. What if the building has a clear sign, but it obviously no longer serves the advertised purpose or is vacant?

A. If it can be determined beyond a reasonable doubt that the building is either vacant or does not serve its specified use, the building is not identifiable. Faded signs, boards, and/or paper covered windows are indicators that a storefront or building is vacant.

Step 5: Count buildings with nonrectangular shapes

Both sides, within study area

Directions

Count and record the number of buildings with nonrectangular shapes on both sides of the street within the study area.

Definitions

- **Buildings with nonrectangular shapes** – are those that do not have simple rectangular profiles as viewed from at least one angle by the passing pedestrian. Visible pitched roofs, bay windows in the roof or foundations lines, and dormers can qualify buildings as nonrectangular. Signs, awnings, entrances, and porches are not considered in the shape of the building.

Examples

Figure 14 – A building with nonrectangular shapes (Location: High St. 55°51'24.7"N 4°14'37.2"W)

Figure 15 – Two rectangular buildings with no curved edges, appearing as simple boxes. (Location: Pacific Quay: 55°51'27.3"N 4°17'33.0"W)

Questions

Q. What if the building is made up of multiple rectangles?

A. If more than one rectangle is visible, the building is not rectangular from at least one angle; therefore, count the building as nonrectangular.

Q. What if the building has a water tower on top of it?

A. If there are any structures incorporated into the building that give it a nonrectangular shape, consider the building nonrectangular.

Step 6: Record outside dining

Your side, within study area

Directions

Observe and record the presence (1) or absence (0) of commercial or public outdoor dining on your side of the street within the study area with a 1 or 0 respectively.

Definitions

- **Outdoor dining** – is defined by dining tables and seating located mostly or completely outside. Even if there are no patrons, there is outdoor dining as long as the tables and chairs are present.

Examples

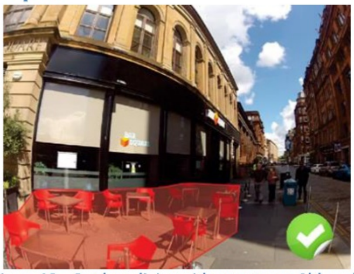


Figure 16 – Outdoor dining with no patrons. Although the tables are not being utilized, this is still considered

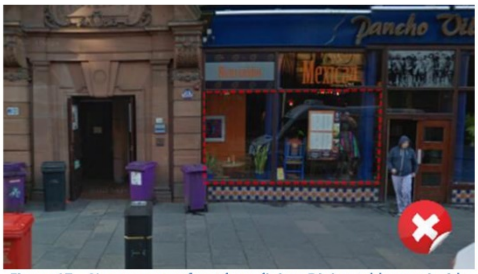


Figure 17 – No presence of outdoor dining. Dining tables are inside the building and visible from the street; however, it does not count as outside dining. (Location: Bell St. 55°51'29.6"N 4°14'44.8"W)

outdoor dining (Location: Bell St. 55°51'29.6"N 4°14'44.8"W)

Frequently asked questions

Q. What if the outdoor dining is closed?

A. If it looks as if the dining could be in operation at some point during the day, count the presence of outdoor dining.

Step 7: Count people
Your side, within the study area

Directions

Walk the length of the sample street segment four times at a reasonable pace (approximately 1 mile per hour or 1.5 kilometers per hour) and count only the visible people located no more than 3m away on the pavement on your side of the street within the study. This count includes those that are coming toward the observer, passing the observer, and those passed by the observer. At the end of the street segment, count the number of people on the cross street at the end of the street segment (if present) that are within 3m. Make sure not to count anyone twice.

Note: Do not count people who are seated at outdoor dining areas.

Definitions

- **Visible people** – includes people walking, running, standing, or sitting – everyone except those at outdoor dining.

Frequently asked questions

Q. Do children and babies in prams or carriers count?

A. Yes, count every person.

Step 8: Estimate noise level.
Your sides, within study area

Directions

Evaluate and record the level of noise while walking the length of the sample street segment (1 = very quiet, 2 = quiet, 3= normal, 4 = loud, 5 = very loud).

Definitions

- **Noise level –** is level of noise coming from cars, trucks, sirens, people, music, construction, etc.

3.2 Enclosure

The degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements.

Step 1: Count long sight lines
Both sides, beyond study area

Directions
Count and record the number of directions (front, right, and left) in which at least one long sight line is visible while walking the length of the street segment (0 min, 3 max). Record a 1 if there is a long sight line in one direction, a 2 for two directions, and a 3 if there is a long sight line in all three directions at least once during the walk-through. Do not count views down cross streets on ends of the street segment.

Note: Do not force it. Long sight lines should be visible without strain.

Definitions
- **Long sight line** – is a line of sight that allows the observer to see at least 300m or about three city blocks into the distance at any point during the walk-through of the street segment.

Examples


Figure 18 – Long sight line straight ahead down the street.

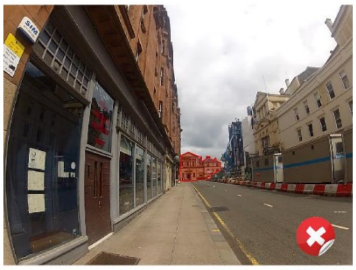


Figure 19 – Long sight line straight ahead is blocked.

Frequently asked questions
Q. Does it count if some of the distant sky is visible through the trees?

A. Only count it if the view is not significantly obstructed. Widely spaced trees may allow for long sight lines.

Q. What if the block is on a downhill slope?

A. If there is a long sight line due to the incline or elevation of the block, count it.

Q. What if the observer can see through the frame of a building that is being constructed?

A. Do not count sight lines through buildings.

Step 2A/2B: Estimate the proportion of street wall.
A – Your side, within study area (up to 3m from pavement edge); B – Opposite side, within study area (up to 3m from pavement edge)

Directions
Estimate and record the proportion of your side of the street that consists of a street wall as a function of the total street front length to the nearest 0.10 decimal. Do the same for the opposite side of the street. Exclude cross streets from the denominator.

Definitions
- **Street wall** – is the effect achieved when structures on a street continuously front the pavement providing a defined street-edge and feeling like a wall (Figure 20). A facade or wall over 1.5m

contributes to the street wall if it is setback no more than 3m from the pavement edge. Gates/fences, greenery, or both over 1.5m that obstruct more than 60 per cent of the view of the space beyond also contribute to the street wall. Lawns, empty plots, driveways, and alleys (or lanes) break the street wall.

Note: Construction sites with solid partitions over 1.5m (and within 3 m of the pavement edge) add to the street wall. If plots under construction are not blocked off and present enough information (all walls), code the street segment imagining the structure(s) to be. If the structure of the open lot cannot be determined (i.e., not enough of it is built yet), there is no street wall.

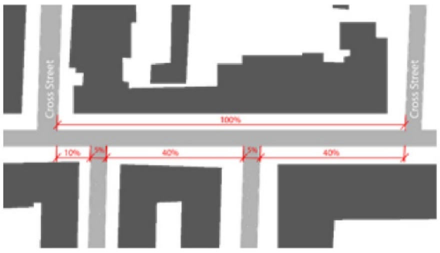


Figure 20 – Example estimate of the proportion of street wall. On one side of the street, the proportion of street wall is estimated at 100 per cent. On the opposite side of the street, the proportion of street wall is also 100 per cent, as the cross streets that break the street frontage are excluded from the denominator (Location: Ingram St. 55°51'34.8"N 4°14'49.0"W)

Examples

Figure 21 – Greenery to the right is over 1.5m high, obstructing more than 60 per cent of the view beyond; therefore, it contributes to the street wall. (Location: Sauchiehall 55°51'58.4"N 4°16'22.4"W)

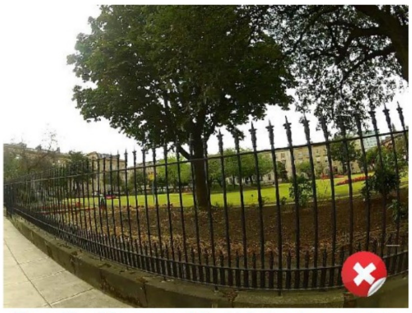


Figure 22 – A fence over 1.5m high that does not obstruct the view of the space beyond; therefore, it does not contribute to street wall. (Location: Blythswood sq. 55°51'47.2"N 4°15'46.6"W)

Figure 23 - Tenements set back less than 3m create a street wall. (Location: Burnbank Gardens 55°52'24.3"N 4°16'18.2"W)

Frequently asked questions

Q. Do cross streets break the street wall?

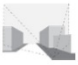
A. No, cross streets do not count as break in the street wall.

Q. What about tenements with stairs coming down to the pavement?

A. If tenements are set back no more than about 3m, they create a street wall.

Q. Do fences or walls add to the street wall?

A. If the fence is over 1.5m tall and obstructs more than 60 per cent of the view overall, it contributes to the street wall.



Step 3A/3B: Estimate the proportion of sky.

A – Ahead, beyond study area; B – Across, beyond study area

Directions

Standing at the beginning of the street segment (typically just past the cross street), look directly ahead without moving the head. Estimate and record the percentage of the sky visible in the frame of vision to the nearest 0.05 decimal (Figure 24). Do the same while looking across the street.

Definitions

- **Frame of vision** –is the "box" that is visible when looking ahead with the observer's line of sight parallel to the ground. To better define the area, make a box with the thumbs and pointer fingers, holding it up to the face. Slowly move the box away from the face until all four sides are visible – this is the "box".

Examples

Figure 24 – Example of the proportion of sky ahead. Estimate of the proportion of sky ahead is approximately 30 per cent.(Location: Ingram St. 55°51'34.8"N 4°14'49.0"W)

Frequently asked questions

Q. What if the building to the across the street is under construction?

A. If it is under construction, there is an obstructed view and therefore the proportion of the sky that will be visible is smaller.

Step 4: Record presence of street trees.*

Your side, within study area

Directions

Observe and record the presence of street trees on your side of the street within the study. Record a 1 if present or 0 if not.

Definition

- **Street trees –** are trees within the study area that occupy at least 20 per cent of the view beyond.

*This physical feature was not included in the original models used in developing this manual as it was not validated for the hypothesized measures of Enclosure, Human scale, or Complexity. It is included here because it is still believed to be of importance, a fact that will be later confirmed or denied through statistical analysis.

Examples

Figure 25 – Presence of street *trees on your side of the street within the study area.* (Location: Lynedoch St. 55°52'06.4"N 4°16'28.1"W)

Figure 26 – A tree beyond the included area of the study area; therefore, it cannot be counted as a street tree. (Location: Blythswood sq. 55°51'47.2"N 4°15'46.6"W)

3.3 Human scale

The size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk.

Step 1: Count long sight lines

Both sides, beyond study area

Directions

The same directions apply as for Enclosure, Step 1. Use that measurement and do not measure twice.

Step 2: Estimate the proportion of windows at street level.

Your side, within study area

Directions

Estimate and record the proportion of street-level façade on your side of the street within the study area that is covered by street-level windows of any size to the nearest 0.10 decimal. The proportion is a function of the total length of the sample street segment (excluding cross streets).

Note: This is not a weighted average and buildings setback from the pavement edge can still contribute to this measure.

Examples

Figure 27 – A few windows (with curtains drawn) at street level that are part of a residential building. (Location: Ingram St. 55°51'34.8"N 4°14'49.0"W)

Figure 28 – Raised first-floor windows well above the street level and view of the pedestrian. These windows do not count because they are not oriented to the pedestrians. (Location: Blythswood sq. 55°51'47.2"N 4°15'46.6"W)

Figure 29 – Commercial shop windows along a street front. (Location: George St. 55°51'38.3"N 4°14'32.4"W)

Frequently asked questions

Q. Do sunken or raised first-floor windows count?

A. Include only the windows at the street level. The windows should be oriented to the eye level of passing pedestrian.

Q. Do windows in buildings under construction count?

A. If the building is being constructed behind a partition or does not have all of its walls yet, windows do not exist for the plot. Buildings that are being maintained or renovated and are not behind solid construction partitions have windows.

Q. If the windows are cloudy, are made of reflective glass, or the curtains are drawn, are they included?

A. Yes, street-level windows are at the scale of and intended for humans and give the impression that there is activity beyond or within the building and should count.

Step 3: Estimate average building height

Your side, within study area

Directions

Observe and record the height of the buildings on your side of the street within the study area as a percentage of the street segment that the buildings occupy. Vacant plots and surface parking are to be excluded. The average may be computed later, after returning from field observations

Note: This measurement is different than other measurements requiring the observer to take a proportion in relation to the total length of the sample street segment. This measurement only applies to the buildings. Only record a zero average height for the street if there are no buildings along your side of the street within the study area.

Definitions

- **Building height** – is the height (in meters) of buildings, assuming an average of about 3m per floor, including the roof floor of buildings with slanted roofs and dormers and any visible sunken floors. The ground floor is 4m tall and the floors above are 3m tall for a typical tenement building around Glasgow. Slanted roofs can add an additional 2-2.5m, depending on the pitch of the roof.

Examples

Figure 30 – Floors of the building on the right are approximately 3m high, so the total building height is approximately 21m. The building on the left has a higher

Figure 31 –The first floor of the building is approximately 4m, and it is suken 1.5 meters from the street level. Adding two 3 meters high floors, the total height of the building is

first floor with approximately 4m, and the tower on the top adds approximately 4m to the building height, making a total of 24 meters tall. (Location: George St. 55°51'38.3"N 4°14'32.4"W)

approximately 11.5 meters. (Location: W Prince's St. 55°52'11.7"N 4°16'08.4"W)

Frequently asked questions

Q. What if the number of floors cannot be discerned from the vantage point of passing pedestrian either because the building is too tall or because the floors are not easily identifiable?

A. Record 60m if the building is known to be over 20 floors and a better estimate cannot be made.

Q. What if the buildings have different heights?

A. Count to the highest floor of the building.

Q. What if it is difficult to determine where one floor starts and the next begins?

A. If the complete height of the building is visible, try using a building with a known height near it as a guide (e.g., it is twice the height of the building with 15 floors; therefore, it has 30 floors).

Note: Make sure to document the percentage of the total street segment length that the building occupies.

Step 4: Count small planters

Your side, within study area

Directions

Count and record all the visible street-level planters on your side of the street within 3m of the pavement edge (i.e., within the included area of the study area). This includes planters on private and public property but not those inside enclosed parks or gardens.

Definitions

- **Small planters** – are any potted arrangement of trees, shrubs, or flowers that are smaller than 1m^2 at their base. The planter should be within 3m of the sidewalk edge and appear to be permanent – i.e., not small enough to be able to be brought inside at the end of the day but not in-ground.

Examples

Figure 32 – Small planters on the side of the pavement. (Location: Bell St. 55°51'29.6"N 4°14'44.8"W)

Figure 33 – Small flower pots, which are easily moveable and therefore do not count as small planters (Location: George St. 55°51'38.3"N 4°14'32.4"W)

Frequently asked questions

Q. If the plants in the pot are dead, do they still count?

A. Count the planter even if the plants are dead because there is the intention of a planter.

Q. What if the planter is on a porch or set back from the sidewalk?

A. If the planter is located no higher than 3m from and no lower than the street level, it counts.

Q. What if the planter is behind a fence?

A. If the planter is visible, it is less than 3 meters from the sidewalk edge, and it is not within an enclosed park or garden, it may be counted.

Step 5A: Count street furniture and other street items.

Your side, within study area

Directions

Count and record visible street furniture and other street items on your side of the street within the study area. Do not count furniture in enclosed parks, gardens, plazas, and courtyards. Record the total number if it is under 40; record "40+" if over.

Note: Do not count tables and chairs used for outdoor dining; these are counted separately. However, if chairs are not associated with outdoor tables, count each chair or stack of chairs. Where there are both stacked tables and chairs, count each table only.

Definitions

- **Street furniture and other street items** – include only the following: tables (without associated chairs), chairs (without associated tables), vendor displays (count one per vendor), ATMs, hanging plants, benches, flower pots, parking meters, pedestrian crossing lights, umbrellas, trash cans (public only), newspaper boxes, mailboxes, bike racks, bollards (count one per set), hydrants, flags, banners, merchandise stands, street vendors, pedestrian-scale street lights (not for cars), phone booths (one per structure), bus stops (count one per stop), and train stations (count one per entrance).

Note: Street furniture and other items are designed for pedestrians. Do not count items that are serve other purposes (e.g., cars), even if they are permanent.

Examples

Figure 34 – 4 street items: 2 bike racks, 1 trashcan and 1 set of bollards. Dining tables to the left do not count in this step. (Location: Ingram St. 55°51'34.8"N 4°14'49.0"W)

Figure 35 – 7 street items: 1 bus top (1), 1 trashcan (2), 1 ATM (3), 2 bike racks (4 and 5) and 2 vendor displays (6 and 7). (Location: George St. 55°51'38.3"N 4°14'32.4"W)

Frequently asked questions

Q. What does not count?

A. If the object is on the list, count it. Objects such as construction materials, street lights, parking and traffic signs, and garbage bags sitting on the curb do not count.

Q. Do furniture displays (retail furniture) count?

A. Yes, they do count.

Q. What if there are over 40 pieces of street furniture?

A. Do not count all the items, simply record "40+."

Step 5B: Count outdoor dining tables

Your side, within study area

Directions

Count and record the number of outdoor tables for dining on your side of the street within the study area.

Note: These are tables with associated chairs or benches.

Examples

Figure 36 –6 outdoor dining tables. (Location: Bell St. 55°51'29.6"N 4°14'44.8"W)

Frequently asked questions

Q. What if there are no chairs associated with the tables, but the tables are clearly intended for outdoor dining?

A. If there are no chairs because they have all been moved elsewhere on the pavement to accommodate a party, the chairs are still associated and the tables can be counted. If the chairs are stacked or if there are no chairs, count the tables as street furniture (5a), as well as each stack of chairs (as described above).

Q. What if two or more tables have been brought together?

A. Two tables brought together can be counted as one, more than that, count separately.

Step 5C: Count other lights
Your side, within study area

Directions

Count and record the number of other lights that are no more than 3m above ground floor on your side of the street within the study area.

Definitions

- **Other lights –** are outdoor lights that are not on poles, usually attached to a building façade or lining the side of a path. Pedestrian-scale street lights on poles are counted in Human scale, Step 5A.

Examples

Figure 37 – 5 other lights integrated into the building facade. (Location: High St. 55°51'24.7"N 4°14'37.2"W)

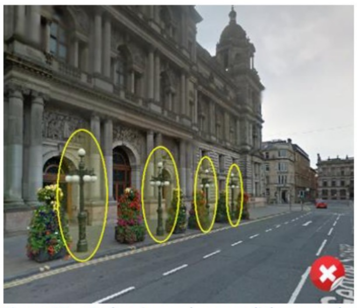


Figure 38 – Pedestrian-scale street lights on poles do not count as other street lights. (Location: George Square 55°51'40.3"N 4°14'56.5"W)

3.4 Transparency

TRANSPARENCY

The degree to which people can see or perceive what lies beyond the edge of a sidewalk/path or public space and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street or other public space.

Step 1: Estimate the proportion of windows at street level
Your side, within study area

Directions

The same directions apply as for Human scale, Step 2. Use that measurement and do not measure twice.

Step 2: Estimate the proportion of street wall
Your side, within study area

Directions

The same directions apply as for Enclosure, Step 2A. Use that measurement and do not measure twice.

Step 3: Estimate the proportion of active uses
Your side, within study area

Directions

Estimate and record the proportion of your side of the street with in the study area that is fronted by active buildings and places. The proportion is a function of the total length of the sample street segment (excluding cross streets), recorded as a decimal to the nearest tenth (0.10). If a building is active, assume all sides are active (even black walls).

Definitions

- **Active use buildings** – are ones in which there is frequent pedestrian traffic (more than 5 people enter/exit while the street is being observed).
- **Always active places –** include parks, stores, restaurants, attached/apartment-style residential buildings, hospitals, and schools
- **Always inactive places –** include construction sites, parking lots, churches, detached/single residence units, and vacant or abandoned plots.

Examples

Figure 39 – Active-use building with frequent pedestrian traffic. (Location: Bath St. 55°51'54.2"N 4°15'59.0"W)

Figure 40 – The building is inactive with no visible activity at street level. (Location: Bath St. 55°51'50.4"N 4°15'27.6"W)

Figure 41 – Active-use building with a store at the street level. (Location: George St. 55°51'38.3"N 4°14'32.4"W)

Frequently asked questions

Q. If the building's use is not known, how should its activity be assessed?

A. If the building appears to be residential, look for signs that indicate people live there (mailboxes, buzzers, window treatments, etc.). If it cannot be determined to be residential or the building is an unknown non-residential building, watch the pedestrian traffic during the time of measuring the street segment and record the building as active if more than 5 people enter or exit while observing the street.

Note: Residential buildings may not be identifiable as defined under Imageability, Step 4, but if the building can be assumed to be residential, it can be considered active.

3.5 Complexity

The visual richness of a place that depends on the variety of the physical environment, specifically the numbers and kinds of buildings, architectural diversity and ornamentation, landscape elements, street furniture, signage, and human activity.

COMPLEXITY

Step 1: Count buildings
Both sides, within study area

Directions

Count and record the number of visible buildings on both sides of the street within the study area.

Note: This includes corner lot buildings and all buildings that are enterable from the study area.

Definitions

- **Visible buildings** – are buildings that can be distinguished by separate doors/entrances, differences in architecture, colour, etc.

Examples

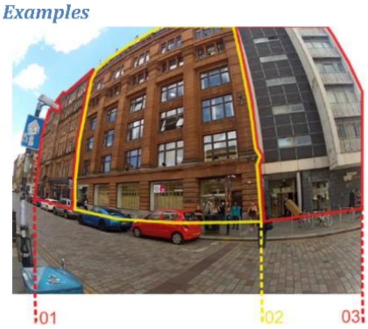


Figure 42 – Three buildings with different primary colours, entrances, and building materials. (Location: Bell St. 55°51’29.6”N 4°14’44.8”W)

Figure 43 – One building on the left side of the street and three buildings on the opposite side of the street. (Location: George St. 55°51’38.3”N 4°14’32.4”W)

Frequently asked questions

Q. What if the pavement in front of a row of tenements is common to all buildings along a street segment?

A. Remember, this is about complexity. If the tenements or other buildings along the street can be distinguished by different doors, different colours, different ornamentation, etc., count them individually.

Step 2A: Count basic building colours.
Both sides, within study area

Directions

Count and record the number of distinct basic building colours on both sides of the street within the study area. Do not distinguish between different shades of the same colour. If the roof is a different from the building, the roof colour will count as an accent colour.

Definitions

- **Basic colour** – is a colour used for the majority of the building's façade.

Examples

Figure 44 - Figure 45 – One basic building colour, yellow. (Location: High St. 55°51'24.7"N 4°14'37.2"W)

Frequently asked questions

Q. What if there is more than one basic colour on a single building?

A. If one colour is the overwhelming majority, count only that colour; if both colours are significant, count the two colours separately.

Step 2B: Count building accent colours.

Both sides, beyond study area

Directions

Count and record the number of distinct accent building/structure/surface colours used on either side of the street and within the study area.

Definitions

- **Accent colour** – is a colour used for building trims and roofs, street objects, awnings, signs and so forth.

Examples

Figure 46 – Four accent building colours: grey, white, black and orange. (Location: High St. 55°51'24.7"N 4°14'37.2"W)

Frequently asked questions

Q. If the accent colour is the same as the basic colour, does it still count?

A. No, if the building is one colour, it has no accent colour.

Step 3: Record outdoor dining
Your side, within study area

Directions

The same directions apply as for Imageability, Step 6. Use that measurement and do not measure twice.

Step 4: Count public art
Your side, within study area

Directions

Count and record the number of individual pieces of public art that are on your side of the street within the study area or intended for viewing from the pavement.

Definitions

- **Public art** – includes monuments, sculptures, murals, and any artistic display that is freely accessible. Art must be the size of a small person or have clear identification indicating its status as art (creator, dedication, year, materials, etc.).

Examples

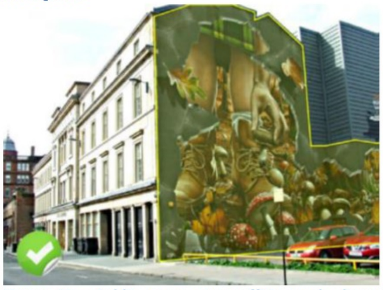


Figure 47 – Public street art: graffiti murals. (Location: Albion St. 55°51’33.1”N 4°14’37.4”W)

Figure 48 – Graffiti tag that does not count as street art. (Location: Mitchell St. 55°51’33.2”N 4°15’21.2”W)

Figure 49 – Two pieces of public art near the Gallery of Modern Art, a sculpture and decorated building façade with stained glass. (Location: Queen St. 55°51’35.0”N 4°15’07.0”W)

Frequently asked questions

Q. What if the art is clearly on someone's property?

A. If the art is visible to the passing pedestrian, it has free access and it can be considered public art.

Q. What if the art is incorporated into a building façade?

A. If the art can be isolated as a specific artistic element of a façade, the building counts as one instance of public art.

Q. How small or simple can the art be?

A. It should be semi-permanent, be intended for the viewing of others, and add to the visual appeal and complexity of the block. Small fountains, and graffiti murals would be included but simple chalk drawings and graffiti tags would not be included.

Step 5: Count pedestrian

Your side, within study area

Directions

The same directions apply as for Imageability, Step 7. Use that measurement and do not measure twice.

4 List of definitions

- **Courtyard** – is a permanent space that people are intended and able to enter.
- **Plaza** – is a large, enterable open space larger than 2 square metres (m^2), often with objects of public art and plants or associated with buildings.
- **Park –** is a place intended for human use and recreation, often with greenery, a playground, etc.
- **Garden** – is an enterable garden larger than 1 m^2.
- **Major landscape features** – are prominent natural landscape elements (e.g., bodies of water, mountain ranges, or human-made features that incorporate the natural environment) that serve as natural landmarks for orientation or reference.
- **Historic buildings** – are buildings determined to be constructed prior to World War II (WW II), usually with a high level of detailing, older building materials (e.g., sandstone), etc. By comparison, post-WW II buildings are usually geometrically and architecturally simple (though sometimes impressive) and have more glass surface area and little detailing.
- **Identifiers** – are clear signs or universal symbols that reveal a building's street-level use. For example, a steeple can identify a church or cathedral, a gas pump can identify a petrol station, tables and chairs can identify a restaurant, mannequins can identify a clothing store, etc. Words can also identify a plot or building (e.g., primary school, pharmacy, café, or brand/franchise names). A name such as "Al's" would not be considered as an identifier; however, "Al's pub" would be considered an identifier.
- **Buildings with nonrectangular shapes** – are those that do not have simple rectangular profiles as viewed from at least one angle by the passing pedestrian. Visible pitched roofs, bay windows in the roof or foundations lines, and dormers can qualify buildings as nonrectangular. Signs, awnings, entrances, and porches are not considered in the shape of the building.
- **Outdoor dining** – is defined by dining tables and seating located mostly or completely outside. Even if there are no patrons, there is outdoor dining as long as the tables and chairs are present.
- **Visible people** – includes people walking, running, standing, or sitting – everyone except those at outdoor dining.
- **Noise level –** is level of noise coming from cars, trucks, sirens, people, music, construction, etc.
- **Long sight line** – is a line of sight that allows the observer to see at least 300m or about three city blocks into the distance at any point during the walk-through of the street segment.
- **Street wall** – is the effect achieved when structures on a street continuously front the pavement providing a defined street-edge and feeling like a wall (Figure 20). A facade or wall over 1.5m contributes to the street wall if it is setback no more than 3m from the pavement edge. Gates/fences, greenery, or both over 1.5m that obstruct more than 60 per cent of the view of the space beyond also contribute to the street wall. Lawns, empty plots, driveways, and alleys break the street wall.
- **Frame of vision** –is the "box" that is visible when looking ahead with the observer's line of sight parallel to the ground. To better define the area, make a box with the thumbs and pointer fingers, holding it up to the face. Slowly move the box away from the face until all four sides are visible – this is the "box".
- **Street trees –** are trees within the study area that occupy at least 20 per cent of the view beyond.
- **Building height** – is the height (in meters) of buildings, assuming an average of about 3m per floor, including the roof floor of buildings with slanted roofs and dormers and any visible sunken floors. The ground floor is 4m tall and the floors above are 3m tall for a typical tenement building around Glasgow. Slanted roofs can add an additional 2-2.5m, depending on the pitch of the roof.

- **Small planters** – are any potted arrangement of trees, shrubs, or flowers that are smaller than $1m^2$ at their base. The planter should be within 3m of the sidewalk edge and appear to be permanent – i.e., not small enough to be able to be brought inside at the end of the day but not in-ground.
- **Street furniture and other street items** – include only the following: tables (without associated chairs), chairs (without associated tables), vendor displays (count one per vendor), ATMs, hanging plants, benches, flower pots, parking meters, pedestrian crossing lights, umbrellas, trash cans (public only), newspaper boxes, mailboxes, bike racks, bollards (count one per set), hydrants, flags, banners, merchandise stands, street vendors, pedestrian-scale street lights (not for cars), phone booths (one per structure), bus stops (count one per stop), and train stations (count one per entrance).
- **Other lights** – are outdoor lights that are not on poles, usually attached to a building façade or lining the side of a path. Pedestrian-scale street lights on poles are counted in Human scale, Step 5A.
- **Active use buildings** – are ones in which there is frequent pedestrian traffic (more than 5 people enter/exit while the street is being observed).
- **Always active places –** include parks, stores, restaurants, attached/apartment-style residential buildings, hospitals, and schools
- **Always inactive places –** include construction sites, parking lots, churches, detached/single residence units, and vacant or abandoned plots.
- **Visible buildings** – are buildings that can be distinguished by separate doors/entrances, differences in architecture, colour, etc.
- **Basic colour** – is a colour used for the majority of the building's façade.
- **Accent colour** – is a colour used for building trims and roofs, street objects, awnings, signs and so forth.
- **Public art** – includes monuments, sculptures, murals, and any artistic display that is freely accessible. Art must be the size of a small person or have clear identification indicating its status as art (creator, dedication, year, materials, etc.).

5 Table of figures

6 References

Abley, S. (2005). Walkability Scoping Paper (pp. 62). Christchurch, New Zealand.

CIHT. (2010). *Manual for Streets 2: Wider Application of the Principles*. London: Chartered Institution of Highways and Transportation.

Clemente, O., Ewing, R., Handy, S., & Brownson, R. (2005). Measuing Urban Design Qualities: An Illustrated Field Manual *Active Living Research Program*. Princeton, NJ: Robert Wood Johnson Foundation.

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine, 70*(6), 816-822. doi: http://dx.doi.org/10.1016/j.socscimed.2009.11.020

Department for Transport. (2007). *Manual for Streets*. London: Thomas Telford Publishing.
Design Council. (2014). Active by Design: Designing places for healthy lives. In D. Council (Ed.): Design Council.
Ewing, R. (2005). Can the Physical Environment Determine Physical Activity Levels? *Exercise and Sport Sciences Reviews, 33*(2), 69-75.
Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association, 76*(3), 265-294.
Ewing, R., & Clemente, O. (2013). *Measuring Urban Design: Metrics for Livable Places*. London: Island Press.
Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: urban design qualities related to walkability. *Journal of Urban Design, 14*(1), 65-84.
Handy, S. (2005). Critical assessment of the literature on the relationships among transportation, land use, and physical activity. *Transportation Research Board and the Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use. Resource paper for TRB Special Report, 282*.
Hillsdon, M., Panter, J., Foster, C., & Jones, A. (2006). The relationship between access and quality of urban green space with population physical activity. *Public Health, 120*(12), 1127-1132. doi: http://dx.doi.org/10.1016/j.puhe.2006.10.007
Jacobs, A. B. (1993). Conclusion: Great Streets and City Planning *Great Streets* (pp. 311-314). Cambridge, MA: MIT Press.
Jacobs, J. (1961). The Uses of Sidewalks: Contact *The Death and Life of Great American Cities*. New York: Random House.
Lindsey, G., Han, Y., Wilson, J., & Yang, J. (2006). Neighborhood correlates of urban trail use. *Journal of Physical Activity & Health, 3*, S139.
Neckermann, K. M., Purciel-Hill, M., Quinn, J. W., & Rundle, A. (2013). Urban Design Qualities for New York City. In R. Ewing & O. Clemente (Eds.), *Measuring Urban Design: Metrics for Livable Places*. London: Island Press.
Purciel, M., & Marrone, E. (2006). Observational Validation of Urban Design Measures for New York City: Field Manual (pp. 27): Robert Wood Johnson Foundation, Active Living Research Program (ALR).
Scottish Government. (2010). *Designing Streets: A Policy Statement for Scotland*. (978-0-7559-8264-6). Edinburgh: RR Donnelley.
Tilt, J. H., Unfried, T. M., & Roca, B. (2007). Using Objective and Subjective Measures of Neighborhood Greenness and Accessible Destinations for Understanding Walking Trips and BMI in Seattle, Washington. *American Journal of Health Promotion, 21*(4s), 371-379. doi: 10.4278/0890-1171-21.4s.371
UN-Habitat. (2013). Streets As Public Spaces and Drivers of Urban Prosperity (pp. 152): United Nations Human Settlements Programme.

7 Appendix

7.1 Appendix A: Metadata sheet

Auditor	
Sample ID	
SIMD data zone	
Street front	
Cross street (from)	
Cross street (to)	
Side of street	
Date (dd/mm/yyyy)	
Start time (00:00)	
End time (00:00)	
Weather (cloudy/partly cloudy/sunny)	
Temperature (°C)	
Method	
Notes	

7.2 Appendix B: Urban Design Qualities and Features Scoring Sheet

#	Quality	Physical feature	Process	Direction	Study area	Recorded value
1.1	Imageability	Courtyards, plazas, and parks	Count	Both sides	Within	
1.2	Imageability	Major landscape features	Count	Both sides	Beyond	
1.3	Imageability	Proportion of historic building frontage	Est. (0.10)	Both sides	Within	
1.4	Imageability	Buildings with identifiers	Count	Both sides	Within	
1.5	Imageability	Buildings with nonrectangular shapes	Count	Both sides	Within	
1.6	Imageability	Presence of outdoor dining	Y=1/N=0	Your side	Within	
1.71	Imageability	Pedestrians (Walk-through 1)	Count	Your side	Within	
1.72	Imageability	Pedestrians (Walk-through 2)	Count	Your side	Within	
1.73	Imageability	Pedestrians (Walk-through 3)	Count	Your side	Within	
1.74	Imageability	Pedestrians (Walk-through 4)	Count	Your side	Within	
1.75	Imageability	Pedestrians (Average)	Average	Your side	Within	
1.8	Imageability	Noise level (1-5; 5 is loudest)	Est. (1-5)	Both sides	Within	
1	Imageability	-	-	-	-	
2.1	Enclosure	Long sight lines (0-3)	Count	Both sides	Beyond	
2.21	Enclosure	Proportion of street wall	Est. (0.10)	Your side	Within	
2.22	Enclosure	Proportion of street wall	Est. (0.10)	Opposite side	Within	
2.31	Enclosure	Proportion of sky	Est. (0.05)	Ahead	Beyond	
2.32	Enclosure	Proportion of sky	Est. (0.05)	Across	Beyond	
2.4	Enclosure	Presence of street trees	Y=1/N=0	Your side	Within	
2	Enclosure	-	-	-		
3.1	Human scale	Long sight lines (0-3)	Count	Both sides	Beyond	
3.2	Human scale	Proportion of street-level façade with windows	Est. (0.10)	Your side	Within	
3.3	Human scale	Average building height	Average	Your side	Within	
3.4	Human scale	Small planters	Count	Your side	Within	
3.51	Human scale	Pieces of street furniture & other street items	Count	Your side	Within	
3.52	Human scale	Outdoor dining tables	Count	Your side	Within	
3.53	Human scale	Other lights	Count	Your side	Within	
3.54	Human scale	All street furniture and other street items	Total	Your side	Within	

3.6	Human scale	Urban designer	Y=1/N=0	-	-	
3	Human scale	-	-	-	-	
4.1	Transparency	Proportion of street-level building façade covered by windows	Est. (0.10)	Your side	Within	
4.2	Transparency	Proportion street wall	Est. (0.10)	Your side	Within	
4.3	Transparency	Proportion active use buildings	Est. (0.10)	Your side	Within	
4	Transparency	-	-	-	-	
5.1	Complexity	Buildings	Count	Both sides	Within	
5.21	Complexity	Basic building colors	Count	Both sides	Within	
5.22	Complexity	Accent colors	Count	Both sides	Within	
5.3	Complexity	Presence of outdoor dining	Y=1/N=0	Your side	Within	
5.4	Complexity	Pieces of public art	Count	Both sides	Within	
5.51	Complexity	Pedestrians (Walk-through 1)	Count	Your side	Within	
5.52	Complexity	Pedestrians (Walk-through 2)	Count	Your side	Within	
5.53	Complexity	Pedestrians (Walk-through 3)	Count	Your side	Within	
5.54	Complexity	Pedestrians (Walk-through 4)	Count	Your side	Within	
5.55	Complexity	Pedestrians (Average)	Count	Your side	Within	
5	Complexity	-	-	-	-	

7.3 Appendix C: Building Scoring Sheet

Your side

Building #	Histori c	I D	Nonre c	Street-level windows (%)	Height (m)	1 Fl actv	% Street
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							

Opposite side

Historic	I D	Nonre c	% Street

25											
26											
27											
28											
29											
30											
Total											
Weighted average proportion											
Proportion											

7.4 Appendix D: Colour Scoring Sheet

Colour	Basic Building Colours	Accent colours
Red		
Orange		
Yellow		
Green		
Blue		
Purple		
Pink		
Brown		
Gray		
White		
Black		
Gold		
Silver		
Total		

7.5 Appendix E: Pedestrian Scoring Sheet

Walk-through #

Pedestrian #	Gender		Age			Activity					
	Male	Female	<18	18-65	>65	Sit	Stand	Walk	Run	Bike	Other
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											

23											
24											
25											
26											
27											
28											
29											
30											
31											
32											
33											
34											
35											
36											
37											
38											
39											
40											
41											
42											
43											
44											
45											
46											
47											
48											
49											
50											
Total											

University of
Strathclyde
Glasgow

GENERAL RISK ASSESSMENT FORM (S20)

Persons who undertake risk assessments must have a level of competence commensurate with the significance of the risks they are assessing. It is the responsibility of each Head of Department or Director of Service to ensure that all staff are adequately trained in the techniques of risk assessment. The University document "Guidance on Carrying Out Risk Assessments" will be available, in due course, to remind assessors of the current practice used by the University. However, reading the aforementioned document will not be a substitute for suitable training.

Prior to the commencement of any work involving non-trivial hazards, a suitable and sufficient assessment of risks should be made and where necessary, effective measures taken to control those risks.

Individuals working under this risk assessment have a legal responsibility to ensure they follow the control measures stipulated to safeguard the health and safety of themselves and others.

SECTION 1

1.1 OPERATION / ACTIVITY	Complete the relevant details of the activity being assessed.		
Title:	Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian activity		
Department:	Architecture		
Location(s) of work:	The University and multiple pedestrian streets throughout the City of Glasgow	**Ref No.**	

Brief description:
Multiple pedestrian streets throughout the City of Glasgow will be audited for urban design qualities and pedestrian activity, requiring travel (via public transportation, walking, and/or biking) to-and-from and at sample locations, on-street scoring, videotaping, and computer analysis.

1.2 PERSON RESPONSIBLE FOR MANAGING THIS WORK			
Name(s):	Prof Sergio Porta	**Position:**	Head of Department
Signature(s):	x [signature]	**Date:**	30/05/14
Department(s):	Department of Architecture		

Issued by Safety Services – Nov 2008 **Page 1 of 7**

SECTION 1 (continued)

1.3 PERSON CONDUCTING THIS ASSESSMENT			
Name:	Prof Sergio Porta	Signature:	x [signature]
Name:		Signature:	x
Name:		Signature:	x
Date risk assessment undertaken:	30/05/14		

1.4 ASSESSMENT REVIEW HISTORY

This assessment should be reviewed immediately if there is any reason to suppose that the original assessment is no longer valid. Otherwise, the assessment should be reviewed annually. The responsible person must ensure that this risk assessment remains valid.

	Review 1	Review 2	Review 3	Review 4
Due date:	__/__/__	__/__/__	__/__/__	__/__/__
Date conducted:	__/__/__	__/__/__	__/__/__	__/__/__
Conducted by:				

SECTION 2

Work Task Identification and Evaluation of Associated Risks Page 3 of 7 Ref No.

Component Task / Situation	Hazards Identified	Hazard Ref No.	Who Might be Harmed and How?	Existing Risk Control Measures (RCM)	Likelihood	Severity	Risk Rating	Risk L, M, H, VH	RCM's Acceptable Y/N
Travel to-and-from sample locations (via public transportation, walking, and/or biking)	**Environmental hazards**: environmental conditions (e.g., rain, sun) **Psychological hazards**: physical violence, bullying or intimidation, leading to stress during and after travel **Working environment hazards**: slippery or uneven ground leading to slips/falls; unsuitable thermal environment, which can lead to hypothermia or heat stress during travel **Working practice hazards**: transport hazards on the road, while travelling or as a pedestrian linked to the speed and external features of vehicles and the road environment	1	Members of the public Staff Students (undergraduate and postgraduate)	Always travel in teams of two or more with charged mobile phones and list of emergency contact number in case of incident Protective equipment including bike helmets, high visibility clothing, and reflectors to be worn when necessary Travel only during the daylight Bring and wear appropriate clothing to keep protected from the elements	2	5	10	H	Y

SECTION 2 (cont.)

Work Task Identification and Evaluation of Associated Risks — **Page 4 of 7** — **Ref No.**

Component Task / Situation	Hazards Identified	Hazard Ref No.	Who Might be Harmed and How?	Existing Risk Control Measures (RCM)	Likelihood	Severity	Risk Rating	Risk L, M, H, VH	RCM's Acceptable Y/N
Data collection at sample location (via on-street scoring and/or videotaping while walking)	**Environmental hazards**: environmental conditions (e.g., rain, sun) during data collection **Psychological hazards**: physical violence, bullying or intimidation, leading to stress during data collection **Working environment hazards**: slippery or uneven ground leading to slips/falls; unsuitable thermal environment, which can lead to hypothermia or heat stress during data collection **Working practice hazards**: transport hazards on the road, while travelling or as a pedestrian linked to the speed and external features of vehicles and the road environment	2	Staff Students (undergraduate and postgraduate)	Always sample in teams of two or more with charged mobile phones and list of emergency contact number in case of incident Protective equipment including bike helmets, high visibility clothing, and reflectors to be worn when necessary Sample only during the daylight Pen-and-paper scoring sheets should not be used while conduction photography at sample locations Bring and wear appropriate clothing to keep protected from the elements	2	5	10	H	Y
Data analysis (via video editing software and other computer programmes)	**Ergonomic hazards**: poor design of work equipment, task layout or frequently repeated tasks giving rise to bad posture and upper limb disorders	3	Staff Students (undergraduate and postgraduate)	Stretch and take breaks from computer when needed	1	2	2	L	Y

SECTION 3

Identified Actions to Improve Control of Unacceptable Risks (as evaluated in Section 2) **Page 5 of 7** **Ref No.**

Hazard Ref No.	Risk	Recommended Additional Risk Control Measures	Implemented Y/N	Action By	Target Date	Completion Date	Revised Risk				Revision of Risk Signed Off
							Likelihood	Severity	Risk Rating	Risk L, M, H	

SECTION 4

RECORD OF SIGNIFICANT FINDINGS	Page 6 of 7 Ref No.

Where this Section is to be given to staff etc., without Sections 2 & 3, please attach to the front of this page, a copy of the relevant Section 1 details.

The significant findings of the risk assessment should include details of the following:

- The identified hazards
- Groups of persons who may be affected
- An evaluation of the risks
- The precautions that are in place (or should be taken) with comments on their effectiveness
- Identified actions to improve control of risks, where necessary

Alternatively, where the work activity/procedure is complex or hazardous, then a written Safe System of Work (SSOW) or Standard Operating Procedure (SOP) is advised that should incorporate the significant findings. Such documents should again, have the relevant Section 1 attached. Please state below whether either a SSOW or SOP is available in this case.

Relevant SSOW available	Yes ☐	No ☐	Relevant SOP available	Yes ☐	No ☐

Significant Findings: (Please use additional pages if further space is required)

SECTION 5

RECEIPT OF SIGNIFICANT FINDINGS OF RISK ASSESSMENT **Page 7 of 7**

Please copy this page if further space is required. **Ref No.**

All individuals working to the risk assessment with the Ref. No. as shown, must sign and date this Section to acknowledge that they have read the relevant risk assessment and are aware of its contents, plus the measures taken (or to be taken by them) to safeguard their health and safety and that of others.

If following review of the assessment revisions are minor, signatories may initial these where they occur in the documentation, to indicate they are aware of the changes made. If revisions are major, it is advisable to produce a new risk assessment and signature page.

NAME (Print)	SIGNATURE	DATE

UNIVERSITY OF STRATHCLYDE

GENERIC FRAMEWORK APPLICATION FORM

APPLICATION FOR GENERIC FRAMEWORK ETHICAL APPROVAL FOR A SERIES OF INVESTIGATIONS AND/OR TEACHING EXERCISES INVOLVING HUMAN PARTICIPANTS

This form should be used for an application for ethical approval for a set of teaching activities or a group of investigations involving human subjects and can be used whether the teaching activities or group of investigations fall within the remit of the University Ethics Committee ("UEC") or a Departmental Ethics Committee ("DEC") (Section B1 a and b of the Code of Practice on Investigations involving Human Beings (the "Code of Practice") sets out the criteria for studies to be considered by the UEC).

Research & Knowledge Exchange Services can advise on whether an application should be considered by the UEC or a Departmental Ethics Committee. Please contact ethics@strath.ac.uk for advice.

1. **Chief Investigator / Course Leader,** (Ordinance 16 member of staff only)

Name: Sergio Porta
Status (professor, senior lecturer, lecturer): Professor
Department: Architecture
Contact details: Telephone: +44 (0)141 548 3016
E-mail: sergio.porta@strath.ac.uk

2. **Other Investigators**
Please list any other investigators who may be involved and give details of any conditions (e.g. professional/medical qualifications) that will be a prerequisite for involvement

Undergraduate student(s) ☒

SP

Name(s): Joseane Ruivo, Cintia Silva De Brito, ~~Fernanda Carvalho Ferreira~~, Savia Porto, and others TBC
Department(s)/School(s): Department of Architecture and the School of Psychological Sciences and Health

Postgraduate students ☒

Name: J. Alexander Maxwell
Department/School: Architecture
Supervisor(s): Prof Sergio Porta and Dr Ombretta Romice
Contact details: +44 (0)798 348 7126; john.maxwell@strath.ac.uk

External students ☐

Professor ☐

Reader ☒

Name: David Rowe
Department/School: School of Psychological Sciences and Health
Contact details: +44 (0)141 548 4069; david.rowe@strath.ac.uk

Senior Lecturer/Lecturer ☒

Name: Ombretta Romice
Department/School: Architecture
Contact details: +44 (0)141 548 3006

Research Assistants ☐

Teaching Assistants ☐

2. Other Investigators (cont.)
Please list any other investigators who may be involved and give details of any conditions (e.g. professional/medical qualifications) that will be a prerequisite for involvement

Admin and Professional support ☐

Technical support ☐

External investigators ☐ specify external institution/organisation

Any conditions that apply:

3. Title of this research/teaching activity:

Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian activity

4. Where will the investigation/teaching activity be conducted?
If not fixed, please specify range/area/type of premises.

This investigation will be conducted both at the University of Strathclyde and several pedestrian streets across the City of Glasgow.

5. Duration of the investigation/teaching activity (years/months):

(Expected) start date: 26 May 2014
(Expected) completion date: 30 September 2015

6. Sponsor:

University of Strathclyde

7. Funding body (if applicable):

N/A

Status of funding application:-

In preparation ☐

Submitted ☐ **Date of submission of proposal**

Accepted ☐ **Date of start of funding**

8. Objectives / Justification of Investigation/Teaching Activity:

Brief Project Background:

Streets are one of the most important and more permanent elements of the public realm. Streets not only provide a link between daily amenities but also a context for public life and physical activity. Urban designers, health researchers and governmental agencies at various scales have placed an increasing priority on the quality of urban environments over the past several years as a way to promote healthier and more sustainable urban environments. This priority is reflected in several recent publications, including: *Designing Streets: A Policy Statement for Scotland* (Scottish Government, 2010), *Streets As Public Spaces and Drivers of Urban Prosperity* (UN-Habitat, 2013), and *Manual for Streets* (DFT, 2007) and *Manual for Streets 2: Wider Application of the Principles* (CIHT, 2010).

One of the most important measures of the overall quality of urban environments is walkability – the measure of how conducive an area is to walking and other pedestrian activity. Though many factors may influence walkability, including weather or the presence of other people, perceptual qualities of urban design are believed to play an important role in promoting pedestrian activity (Figure 1).

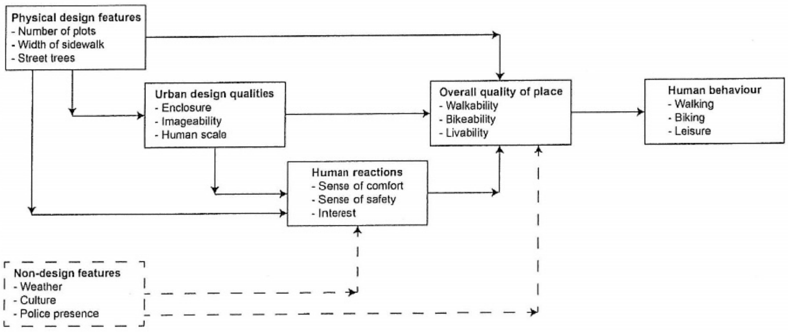


Figure 1: Conceptual framework for the proposed study, *adapted from Figure 1 in Ewing and Handy (2009, p. 67)*

Recently, the tools and techniques for objectively measuring urban design features and qualities have greatly improved. Likewise, similar advances have been made in measures of pedestrian activity, especially walking. However, there still remains a lack of empirical evidence to support claims about the degree to which perceptual urban design qualities may influence pedestrian activity.

The Urban Design Studies Unit (Department of Architecture) and the Physical Activity for Health Research Group (School of Psychological Sciences and Health) have extensive experience and knowledge in the measurement of urban design features and pedestrian activity. In collaboration with researchers and practitioners in both Europe (Gehl Architects) and the United States (Reid Ewing from the University of Utah), the overall aim of this research is to capitalize on many of the recent advances in technologies and methodologies in order to address this gap in

8. Objectives / Justification of Investigation/Teaching Activity (cont.):

knowledge. Over the course of the next year, more than 690 streetscapes from across each of Glasgow's data zones (according to the Scottish Index of Multiple Deprivation) will be visually audited using videotaping, pen-and-paper audits, and computer analysis for urban design qualities and several dimensions of pedestrian activity. This is an exciting opportunity for both undergraduate and postgraduate students to join an interdisciplinary team and play an essential role in helping to pilot test protocols, collect data, and develop new ideas – bringing us one step closer to understanding the role of design in creating healthier urban environments.

References:

EWING, R. & HANDY, S. 2009. Measuring the unmeasurable: urban design qualities related to walkability. *Journal of Urban Design,* 14, 65-84.

CIHT 2010. *Manual for Streets 2: Wider Application of the Principles,* London, Chartered Institution of Highways and Transportation.

DEPARTMENT FOR TRANSPORT 2007. *Manual for Streets,* London, Thomas Telford Publishing.

SCOTTISH GOVERNMENT 2010. Designing Streets: A Policy Statement for Scotland. Edinburgh: RR Donnelley.

UN-HABITAT 2013. Streets As Public Spaces and Drivers of Urban Prosperity. United Nations Human Settlements Programme.

9. Details of participants (please provide details for *each* group of participants who will be recruited to take part in the investigations/teaching exercise by answering the following questions):

a. What are the principal inclusion criteria (please justify)?

University staff:

All University staff must be mentally and physically able to supervise and advise during the course of the investigation.

Undergraduate/Postgraduate students:

Age (range): 18 and over
Gender of volunteers: Male and female

All undergraduate and postgraduate student participants must be mentally and physically willing and able to complete tasks* required for the auditing of urban design qualities and pedestrian activity.

9. Details of participants (please provide details for *each* group of participants who will be recruited to take part in the investigations/teaching exercise by answering the following questions) (cont.):

*Tasks may include: (1) on-street collection of data (via scoring sheet or video camera) while walking through various pedestrian streets, (2) using computer for post-collection analysis, and (3) ability to travel to-and-from sample locations (via walking, public transportation, and/or biking).

b. What are the principal exclusion criteria (please justify)?

All not meeting the inclusion criteria above will be excluded from the investigation.

c. Will any of the participants be from any of the following groups?

Are unable to consent for themselves or have significant learning difficulties and/or cognitive impairment of a nature and extent that would affect their ability to give informed voluntary consent	☐
Are severely ill or have a terminal illness	☐
Are prisoners or young offenders, or are awaiting trial for a crime or offence that is relevant to the project	☐
Are potentially subject to coercive measures by government, such as detention, restrictions on movement, deportation or repatriation	☐
Live in or are connected to an institutional environment	☐
Are in a situation of special vulnerability, e.g. women of childbearing potential where the investigation might carry any risk to pregnancy or to a foetus, or persons with addictions	☐
Have a physical disability or a chronic physical condition relevant to the subject of the investigation.	☐

Have the appropriate Participant Information Sheets and Consent Forms been prepared for each group? Yes☒ No☐

If 'NO', please explain

Remember to complete the checklist of documents at the end of this application form.

10. Recruitment (Please refer to the guidance in Section B4b of the Code of Practice):

How will participants be recruited:

10. Recruitment (Please refer to the guidance in Section B4b of the Code of Practice):

Letter ☐
Advertising notice ☐
In person: to groups ☐ **to individuals** ☐

If 'In person to Individuals', please give details:

Other:

Initial contact will be made with potential undergraduate student investigators via informal emails and oral announcements from the postgraduate student(s) and staff mentioned above. All those interested will be provided with the brief project background (see above). Following initial contact with potential investigators, a participant information sheet will be provided to all investigators along with the appropriate consent form. Upon arriving at the initial project meeting, investigators will be asked to sign and date the consent forms.

Are recruitment procedures consistent with the need to obtain informed consent? ☒

11. <u>What consents will be sought and how</u>? Please refer to the guidance in Section B4c of the Code of Practice .

Consent will be sought by way of oral communication of project details and a subsequent signing of consent forms.

12. <u>Methodology</u>

Are any of the categories mentioned in the Code of Practice Section B1a (project considerations) applicable to this investigation/teaching exercise?

Yes ☐ No ☒

If yes please detail:

PLEASE NOTE: This application will be assessed on the appropriateness and necessity of the methodologies and techniques described herein. If approved, ethical approval is only given to the methodologies and techniques described in this application.

12. <u>Methodology (cont.)</u>

Design: Please list all methodologies you can reasonably foresee being part of this generic framework application:

The design of this investigation will involve field collection of data and lab/office analysis on a computer.

Techniques: Please list all techniques you can reasonably foresee being part of this generic framework application. With as much detail as possible, describe what is required of participants.

<u>Field collection of data</u>

Field collection of data will be done using both pen-and-paper scoring sheet and person-mounted video cameras (e.g., GoPro cameras with head and chest mounts) while slowly walking through pedestrian street environments.

<u>Lab/office computer analysis</u>

Computer analysis of data collected in the field will be analysed using computer-based software (e.g., Microsoft Excel, ArcGIS, AutoCAD, SigmaPlot).

13. <u>Data collection, storage and security:</u>

Please explain how data is handled, specifying whether it will be fully anonymised, pseudo-anonymised, or just confidential, and whether it will be destroyed after use.

All data collected in this study will be kept confidential and the names of the investigators will only be included in subsequent publications or published materials with their permission.

Please state how and where data will be stored, who has access to it, and for how long it will be stored.

Data will be stored at the University on a password protected computer hard drive and backed up using a password protected cloud-based program (e.g., Dropbox).

Will anyone other than the named investigators have access to data?

Yes ☒ No ☒

If yes please detail: Results from this research may be shared with others (e.g., Glasgow City Council; however, names and identities of participants will not be shared without express permission.

14. Potential risks or hazards:
(Details of all risks, hazards and discomforts to participants and researchers and efforts to ameliorate these before, during and after the participant's involvement)

Potential risks, hazards and discomforts are detailed in the attached risk assessment form, which will also be provided to all participants of this investigation.

15. Ethical issues

The main ethical issue related to this investigation involves the collection potentially harmful data while videotaping in public street environments. Harmful data could include for example incidents of crime witnessed in a public place.

All efforts will be made during the collection, analysis, reporting, and storing of all data to avoid collecting and disclosing information that would be harmful to those potentially captured during on-street videotaping. The data collected for this investigation will mostly be reported in terms of mathematical values and statistical figures, without the need to disclose any personal information. However, certain images may be used in conjunction with these results to further illustrate key findings.

This is in keeping with American Psychological Association *Ethics Code* (effective 1 June 2010) Section 8.03[1] and the British Psychological Society *Code of Ethics and Conduct* (effective August 2009) Section 1.3.ix[2].

16. Any payment to be made:

N/A

17. What debriefing, if any, will be given to participants?

All participants will be debriefed on the risks and ethical concerns related to this study in addition to the tasks and skills necessary to complete this investigation prior to beginning.

[1] Informed Consent for Recording Voices and Images in Research Psychologists obtain informed consent from research participants prior to recording their voices or images for data collection unless (1) the research consists solely of naturalistic observations in public places, and it is not anticipated that the recording will be used in a manner that could cause personal identification or harm, or (2) the research design includes deception, and consent for the use of the recording is obtained during debriefing. (See also Standard 8.07, Deception in Research.)
[2] Unless informed consent has been obtained, restrict research based upon observations of public behaviour to those situations in which persons being studied would reasonably expect to be observed by strangers, with reference to local cultural values and to the privacy of persons who, even while in a public space, may believe they are unobserved.

18. How will the outcomes of the study be disseminated?
Will you seek to publish the results?

It is anticipated that the outcomes of this study will be disseminated through the publication of peer-reviewed journal articles, conference papers and presentations.

19. Nominated person/s (and contact details) to whom participants' concerns/questions should be directed before, during or after the investigation.

Prof Sergio Porta (contact details provided above)

20. Minimum previous experience of the investigator(s) with the procedures involved.

Staff and postgraduate investigators will have significant experience with the procedures involved and all others (i.e., undergraduates) will be properly trained in all required procedures.

21. Management risk assessment
The Code of Practice on Investigations involving Human Beings requires that all investigations involving humans as subjects should be subject to management risk assessment as well as ethical scrutiny. When considering management risk, Senior Officers will consider factors including, but not limited to, the following:

1. Risk to reputation of University and risk of litigation and/or insurance claims. This risk maybe caused by:
    - harm to volunteers and wider community
    - poor research strategy
    - breach of statutory framework or contractual obligations
    - project not being carried out according to protocol
    - inadequate or inappropriate insurance cover.

2. Risk to research completion. This risk maybe caused by:
    - failure to properly carry out research
    - failure to proper supervise students
    - inadequate resources and/or facilities
    - inexperienced staff.

3. Risk to dissemination and use of research results. This risk maybe caused by lack of resources or failure to identify and act upon intellectual property in results.

4. Risk to researchers – career and reputation. This risk maybe caused by misconduct or non-completion of research.

21. Management risk assessment (cont.)

The management risk assessment will consider the University's context, in particular:

- Research and Development Strategy, including the objective of the University in general, and the objective of University research generally and within the relevant faulty/department.
- Research and Development Structure and Systems. In particular the support provided by the University's structure to reduce the risks posed by research and by this investigation, and the systems in place to monitor and respond to the risks.

1. Title of investigation:

   Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian behaviour

2. Chief Investigator : ....Prof Sergio Porta
3. Is it proposed the University will sponsor the investigation (i.e. have responsibility for overall management of the investigation)?
   Yes ☒ No ☐ If no, who is the Sponsor? ....
4. Are you aware of any issues relevant to the University's insurance cover? For example is this a clinical trial and/or are you offering no-fault compensation to volunteers?
   Yes ☐ No ☒
   If yes, what are those issues? ....
5. Are you aware of any issues relevant to the University's assessment of management risk of this project? Please see attached for examples of possible management risk issues.
   Yes ☒ No ☐
   If yes, what are those issues? ....Please see risk assessment attached

Signature of Chief Investigator: ......[signature].......

Date: ..02/06/14..........

Investigator and Head of Department Declaration

I have read the University's Code of Practice on Investigations involving Human Beings and have completed this application accordingly.

Signature of Chief Investigator/Course Leader Please also print name below

.... Sergio Porta

Signature of Head of Department Please also print name below

....

Date: 02/06/14

Head of Dept statement on Sponsorship
(only for university sponsored projects under the remit of the DEC with no external funding and no NHS involvement)

This application requires the University to sponsor the investigation. I am aware of the implications of University sponsorship of the investigation and have assessed this investigation with respect to sponsorship and management risk. As this particular investigation is within the remit of the DEC and has no external funding and no NHS involvement, I agree on behalf of the University that the University is the appropriate sponsor of the investigation and there are no management risks posed by the investigation.

If not applicable, cross here

Signature of Head of Department Please also print name below

.... SERGIO PORTA

Date: 02/06/14

* *

For applications to the University Ethics Committee the completed form should be sent (electronically with signed hard copy to follow) to Research & Knowledge Exchange Services in the first instance.

Checklist of enclosed documents

It is appreciated that in the case of generic framework applications that it is not always possible to give examples of every possible document within the framework. Supporting documentation may therefore fall within one of the following categories:-

Examples - full documentation is not provided, but examples given.

Standardised documents – these may be used where the investigator/course leader is able to produce a standard set of documentation which will not vary substantially for each investigation/teaching exercise.

Devolve to DEC (where investigation/teaching activities within remit of UEC): where it is not possible for documents to be produced at the application stage, the UEC may devolve approval of supporting documents to the relevant DEC.

Document	**Examples Enclosed**	**Standardised documents enclosed**	**Devolve to DEC**	**N/A**
Participant information sheet(s)	☒	☐	☐	☐
Consent form(s)	☒	☐	☐	☐
Sample questionnaire(s)	☐	☐	☐	☒
Sample interview format(s)	☐	☐	☐	☒
Sample advertisement(s)	☐	☐	☐	☒
Any other documents (please specify below) Risk assessment	☒ ☐ ☐ ☐	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐

Please check your documentation specifications before submitting this application:

Has a consent form and a participant information sheet been developed for every *group* of participants ? ☒

Has a consent form been developed for each relevant procedure? ☒

Does all advertisement and correspondence carry the University Logo? N/A

Are questionnaires pitched at the appropriate level for participants? N/A

Does the consent form make clear that participants are free to withdraw at any time without giving reason, and (if appropriate) without effecting their situation (school/work/care etc)? ☒

Do participants have adequate time to consider involvement prior to giving informed consent? ☒

Participant Information Sheet for Urban Design Studies Unit

Name of department: Architecture
Title of the study: Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian activity

Introduction
This research project is being conducted by the primary investigators from the University of Strathclyde, Prof Sergio Porta (Department of Architecture), Dr David Rowe (School of Psychological Sciences and Health), and Mr John Alexander Maxwell (Department of Architecture). While this research project serves as an integral part of Mr Maxwell's PhD thesis and a bulk of the work will be carried out by him, he will also be under the direct supervision of Prof Porta and Dr Rowe. Below is a list of contact information for all three of the primary investigators:

Name: Sergio Porta (Professor)
Department/School: Architecture
Contact details: +44(0)141 548 3016; sergio.porta@strath.ac.uk

Name: David Rowe (Reader)
Department/School: School of Psychological Sciences and Health
Contact details: +44 (0)141 548 4069; david.rowe@strath.ac.uk

Name: J. Alexander Maxwell (Postgraduate student)
Department/School: Architecture
Supervisor(s): Prof Sergio Porta and Dr Ombretta Romice
Contact details: +44 (0)798 348 7126; john.maxwell@strath.ac.uk

What is the purpose of this investigation?
The overall aim of this research project is to test new methodologies and collect data necessary to measure the urban design qualities of pedestrian street environments and pedestrian behaviours. Over the course of the next year, more than 690 streetscapes from across each of Glasgow's data zones (according to the Scottish Index of Multiple Deprivation) will be visually audited for urban design qualities and later validated against several dimensions of pedestrian activity. This is an exciting opportunity for both undergraduate and postgraduate students to join an interdisciplinary team and play an essential role in helping to pilot test protocols, collect data, and develop new ideas – bringing us one step closer to understanding the role of design in creating healthier urban environments.

Do you have to take part?
Participants' decision to take part in the investigation is voluntary, and refusing to participate or withdrawing participation, will not affect any other aspects of the way a person is treated (i.e. participants have a right to withdraw without detriment*).

*Note: If withdrawing or refusing to participate, the participant cannot be credited for contributions to the investigation, which may affect their ability to meet course/programme requirements.

What will you do in the project?
If you choose to participate in this study, the overall study will last until the end of September 2015**, and you will be required to:

- Attend regular meetings and team discussions at the University of Strathclyde
- Audit multiple (upwards of 694) pedestrian streets throughout the City of Glasgow for urban design qualities and pedestrian activity, requiring travel (via public transportation, walking, and/or biking) to-and-from and at sample locations, on-street scoring, videotaping, and computer analysis

Why have you been invited to take part?
You have been invited to participate in this study because you are an undergraduate student at the University of Strathclyde, 18 years or older, and mentally and physically willing and able to complete tasks required for the auditing of urban design qualities and pedestrian activity.

Tasks may include: (1) on-street collection of data (via scoring sheet or video camera) while walking through various pedestrian streets, (2) using computer for post-collection analysis, and (3) ability to travel to-and-from sample locations (via walking, public transportation, and/or biking).

What are the potential risks to you in taking part?
Please see attached risk assessment form for complete list of risk associated with the project, along with all measures that will be taken to ensure your personal safety.

What happens to the information in the project?
Your name and any data related to your person will not be used without your expressed permission.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

What happens next?
If you are happy to be involved in the project, you will be asked to sign a consent form to confirm this.

If you do not want to be involved in the project then thank you for your attention.

Results from this investigation may be published and you may be contacted in the future for further feedback regarding the research project.

This investigation was granted ethical approval by the Department of Architecture Ethics Committee.

**Though the overall study is meant to last until September 2015, the bulk of the data collection and analysis will be done during the summer of 2014 and the summer of 2015 (if needed).

If you have any questions/concerns, during or after the investigation, or wish to contact an independent person to whom any questions may be directed or further information may be sought from, please contact:

Secretary to the University Ethics Committee
Research & Knowledge Exchange Services
University of Strathclyde
Graham Hills Building
50 George Street
Glasgow
G1 1QE

Telephone: 0141 548 3707
Email: ethics@strath.ac.uk

Consent Form for Urban Design Studies Unit

Name of department: Architecture
Title of the study: Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian behaviour

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, without having to give a reason and without any consequences.
- I understand that I can withdraw my data from the study at any time.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project
- I consent to being audio and video recorded as part of the project [delete which is not being used] Yes/ No

(PRINT NAME) SAVIA COIMBRA PORTO SANTOS

Signature of Participant: [signature] Date: 02/06/2014

(PRINT NAME) JOSEANE DE OLIVEIRA RUIVO

Signature of Participant: Joseane Ruivo Date: 02/06/2014

(PRINT NAME) CÍNTIA SILVA DE BRITO

Signature of Participant: Cíntia Brito Date: 02/06/2014

(PRINT NAME) ALISSON PAZETTO DE OLIVEIRA

Signature of Participant: [signature] Date: 02/06/2014

University of Strathclyde Glasgow

Participant Information Sheet for Urban Design Studies Unit

Name of department: Architecture
Title of the study: Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian activity

Introduction
This research project is being conducted by the primary investigators from the University of Strathclyde, Prof Sergio Porta (Department of Architecture), Dr David Rowe (School of Psychological Sciences and Health), and Mr John Alexander Maxwell (Department of Architecture). While this research project serves as an integral part of Mr Maxwell's PhD thesis and a bulk of the work will be carried out by him, he will also be under the direct supervision of Prof Porta and Dr Rowe. Below is a list of contact information for all three of the primary investigators:

Name: Sergio Porta (Professor)
Department/School: Architecture
Contact details: +44(0)141 548 3016; sergio.porta@strath.ac.uk

Name: David Rowe (Reader)
Department/School: School of Psychological Sciences and Health
Contact details: +44 (0)141 548 4069; david.rowe@strath.ac.uk

Name: J. Alexander Maxwell (Postgraduate student)
Department/School: Architecture
Supervisor(s): Prof Sergio Porta and Dr Ombretta Romice
Contact details: +44 (0)798 348 7126; john.maxwell@strath.ac.uk

What is the purpose of this investigation?
The overall aim of this research project is to test new methodologies and collect data necessary to measure the urban design qualities of pedestrian street environments and pedestrian behaviours. Over the course of the next year, more than 690 streetscapes from across each of Glasgow's data zones (according to the Scottish Index of Multiple Deprivation) will be visually audited for urban design qualities and later validated against several dimensions of pedestrian activity. This is an exciting opportunity for both undergraduate and postgraduate students to join an interdisciplinary team and play an essential role in helping to pilot test protocols, collect data, and develop new ideas – bringing us one step closer to understanding the role of design in creating healthier urban environments.

Do you have to take part?
Participants' decision to take part in the investigation is voluntary, and refusing to participate or withdrawing participation, will not affect any other aspects of the way a person is treated (i.e. participants have a right to withdraw without detriment*).

*Note: If withdrawing or refusing to participate, the participant cannot be credited for contributions to the investigation, which may affect their ability to meet course/programme requirements.

University of Strathclyde Glasgow

What will you do in the project?
If you choose to participate in this study, the overall study will last until the end of September 2015**, and you will be required to:

- Attend regular meetings and team discussions at the University of Strathclyde
- Audit multiple (upwards of 694) pedestrian streets throughout the City of Glasgow for urban design qualities and pedestrian activity, requiring travel (via public transportation, walking, and/or biking) to-and-from and at sample locations, on-street scoring, videotaping, and computer analysis

Why have you been invited to take part?
You have been invited to participate in this study because you are an undergraduate student at the University of Strathclyde, 18 years or older, and mentally and physically willing and able to complete tasks required for the auditing of urban design qualities and pedestrian activity.

Tasks may include: (1) on-street collection of data (via scoring sheet or video camera) while walking through various pedestrian streets, (2) using computer for post-collection analysis, and (3) ability to travel to-and-from sample locations (via walking, public transportation, and/or biking).

What are the potential risks to you in taking part?
Please see attached risk assessment form for complete list of risk associated with the project, along with all measures that will be taken to ensure your personal safety.

What happens to the information in the project?
Your name and any data related to your person will not be used without your expressed permission.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998.

Thank you for reading this information – please ask any questions if you are unsure about what is written here.

What happens next?
If you are happy to be involved in the project, you will be asked to sign a consent form to confirm this.

If you do not want to be involved in the project then thank you for your attention.

Results from this investigation may be published and you may be contacted in the future for further feedback regarding the research project.

This investigation was granted ethical approval by the Department of Architecture Ethics Committee.

**Though the overall study is meant to last until September 2015, the bulk of the data collection and analysis will be done during the summer of 2014 and the summer of 2015 (if needed).

If you have any questions/concerns, during or after the investigation, or wish to contact an independent person to whom any questions may be directed or further information may be sought from, please contact:

Secretary to the University Ethics Committee
Research & Knowledge Exchange Services
University of Strathclyde
Graham Hills Building
50 George Street
Glasgow
G1 1QE

Telephone: 0141 548 3707
Email: ethics@strath.ac.uk

Consent Form for Urban Design Studies Unit

Name of department: Architecture
Title of the study: Designing for life between buildings: Measuring the influence of urban design qualities on pedestrian behaviour

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, without having to give a reason and without any consequences.
- I understand that I can withdraw my data from the study at any time.
- I understand that any information recorded in the investigation will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project
- I consent to being audio and video recorded as part of the project [delete which is not being used] Yes/ No

(PRINT NAME) MONIQUE VALE SZPOGANICZ

Signature of Participant: moSzpoganicz Date: 05/06/15.

(PRINT NAME) PAOLA BUCCI LEAL

Signature of Participant: [signature] Date: 05/06/15

(PRINT NAME)

Signature of Participant: Date:

(PRINT NAME)

Signature of Participant: Date:

VITA

VITA

J. Alexander Maxwell

Gonzaga University
Department of Civil Engineering
502 East Boone Avenue
Spokane, Washington 99258
(509) 313-3552

EDUCATION

(2016) Ph.D. in Urban Design (ABD), University of Strathclyde, Department of Architecture
2011 M.S. in Environmental Science and Engineering, Clarkson University, Institute for a Sustainable Environment
2009 B.S. in Civil Engineering, Gonzaga University, Department of Civil Engineering

PROFESSIONAL APPOINTMENTS

2016- Lecturer, Gonzaga University, Department of Civil Engineering
2015-2016 Adjunct Instructor, Gonzaga University, Department of Civil Engineering
2012 Director of Zambia Engineering Study Abroad Program, Gonzaga University, Department of Civil Engineering
2011-2012 Lecturer, Gonzaga University, Department of Civil Engineering

PUBLICATIONS

Refereed Journal Articles

Blackwell, B. D., Driscoll, C. T., Maxwell, J. A., & Holsen, T. M. (2014). Changing climate alters inputs and pathways of mercury deposition to forested ecosystems. Biogeochemistry, 119(1-3), 215-228.

Porta, S., Romice, O., Maxwell, J. A., Russell, P., & Baird, D. (2014). Alterations in scale: patterns of change in main street networks across time and space. Urban Studies, 51(16), 3383-3400.
Maxwell, J. A., Holsen, T. M., & Mondal, S. (2013). Gaseous Elemental Mercury (GEM) Emissions from Snow Surfaces in Northern New York. PloS one, 8(7), e69342.

Book Chapters

Maxwell, J. A. (2008). Motivation. In B. A. Striebig & S. Norwood (Eds.), WATER in Benin: An Example of Sustainable Development in Benin, West Africa (pp. 7-14). Spokane, WA: Lulu.

Conference Proceedings

London, M. R., & Cadwell, J. R., & Maxwell, A. (2011, June), Development of a Study Abroad Experience in Africa as a Recruitment and Retention Tool for Women in Engineering. Paper presented at 2011 Annual Conference & Exposition, Vancouver, BC. Available from: https://peer.asee.org/17763

Web-Based Publications

J. A. Maxwell & C. R. Wolfe. (2014, March 19). City main street networks show a drastic shift away from historic patterns of human-scale design. London School of Economics, USAPP – American Politics and Policy. London, UK. Available from: http://bit.ly/1j2IBDb.

Other Publications

United Nations Human Settlements Program (UN-Habitat). (2016). *Guiding Principles for City Climate Action Planning: Glasgow, Scotland (UK) Assessment Report*. Nairobi, Kenya: J. A. Maxwell & W. Lynn. (*In review*)
United Nations Human Settlements Program (UN-Habitat). (2015). Guiding Principles for City Climate Action Planning. Nairobi, Kenya: J. A. Maxwell et al. Available from: http://unhabitat.org/guiding-principles-for-climate-city-planning-action/

UN-Habitat. (2015). Urbanization and Climate Change in Small Island Developing States. Nairobi, Kenya: J. A. Maxwell et al. Available from: http://unhabitat.org/books/urbanization-and-climate-change-in-small-island-developing-states/

Glasgow Chamber of Commerce & Urban Land Institute. (2015). Tomorrow's City Centre: Glasgow Agenda. Glasgow, UK: G. Clark & J. A. Maxwell. Available from: http://issuu.com/glasgowchamberofcommerce/docs/gcc_whitepaper/1?e=15550721/11380793.

C. R. Wolfe & J. A. Maxwell. (2014, November 12). Using 'plot-based urbanism' to reclaim the basic unit of the city. MyUrbanist.com. Available from: http://www.myurbanist.com/archives/10986.

AWARDS AND HONORS

2014 Postgraduate Travel Award, University of Strathclyde, Glasgow, Scotland, UK

2013 Mac Robertson Travel Scholarship, University of Glasgow & University of Strathclyde, Glasgow, Scotland, UK

2013 Engineering and Physical Sciences Research Council International Exchange Grant, MIT-Singapore University of Technology and Design, City Form Lab, Singapore, Singapore

2012 Royal Society of Arts Fellowship, London, England, UK

2012 Fulbright Postgraduate Research Award, US-UK Fulbright Commission, University of Strathclyde, Glasgow, Scotland, UK

2011 William Brewster Snow Award, American Academy of Environmental Engineers and Scientists, Washington, D.C., USA

2009 National Science Foundation (NSF) K-12 Teaching Fellow, Clarkson University, Potsdam, NY, USA

2009 American Society of Civil Engineers (ASCE) Student Scholarship, ASCE Inland Empire Section, Spokane, WA, USA

2008 NSF Research Experience for Undergraduates (REU) Fellow, Clarkson University, Potsdam, NY, USA

2005 Trustees Scholarship, Gonzaga University, Spokane, WA, USA

2005 Ignatian Leaders Scholarship, Gonzaga University, Spokane, WA, USA

INVITED TALKS

2016 "Applications of the Guiding Principles for City Climate Action Planning: Glasgow Case Study," Guiding Principles for City Climate Action Planning Initiative: Meeting of the endorsing partners, UN-Habitat, Bonn, Germany, July 4

2016 "Introduction to the Guiding Principles for City Climate Action Planning," Climate Change Public Bodies' Duties Statutory Reporting and Climate Change Assessment Tool (C-CAT) workshop, Glasgow City Council, Glasgow, UK, June 13

2015 "Tomorrow's City Centre: Glasgow Agenda," 2015 Universitas 21 Summer on Cities and Citizens in the Digital Age, University of Glasgow, Glasgow, UK, July 13

CONFERENCE ACTIVITY

Conferences Organized

2015 Second Expert Group Meeting (EGM) on City Climate Action Plans, Bonn, Germany, June 11-12

2015 First EGM on Guidelines for City Climate Action Plans, Oslo, Norway, March 02-03

2014 Summit on Plot-Based Urbanism, Glasgow, Scotland, UK, October 27-28

Papers Presented

2016 "Applications of the Guiding Principles for City Climate Action Planning: Glasgow Case Study," 7th Global Forum on Urban Resilience & Adaptation, ICLEI-Local Governments for Sustainability, Bonn, Germany, July 7

2015 "Designing for 'life between buildings': Measuring the influence of urban design qualities on pedestrian activity," Faculty of Engineering Research Presentation Day (RPD), University of Strathclyde, Glasgow, UK, June 24

2013 "Pro-Poor Urban Planning and Design: Synthesizing and Adapting the Principles and Practices of Plot-Based Urbanism to Address Issues with Informal Settlements," Association of European Schools of

Planning (AESOP) 2013 PhD Workshop, Joint AESOP/American Collegiate Schools of Planning Congress, Belfast, UK, July 11

2013 "Plot-Based Urbanism and Sprawling Slums in the Global South," Faculty of Engineering RPD, University of Strathclyde, Glasgow, UK, June 27

2011 "Gaseous Elemental Mercury Emissions From the Forest Floor in New York's Adirondack Park," 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia, Canada, July 24-29

2011 "Snow Surface-to-Air Exchange of Gaseous Elemental Mercury in Northern New York, USA," 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia, Canada, July 24-29

2011 "Development of a Study Abroad Experience in Africa as a Recruitment and Retention Tool for Women in Engineering," American Society for Engineering Education 188th ASEE Annual Conference & Exposition, Vancouver, Canada, 26-29 June 2011

2011 "Mercury Inputs, Outputs, Cycling, And Ambient Concentrations Under the Forest Canopy in The Adirondacks Of New York." 8th Annual Adirondack Research Forum, Old Forge, NY, USA, March 2

2010 "Mercury Inputs, Outputs, Cycling, and Ambient Concentrations Under the Forest Canopy in the Adirondacks of New York," The Geological Society of America Northeastern Section (45th Annual) and Southeastern Section (59th Annual) Joint Meeting, Baltimore, MD, USA, March 15

2009 "Technology and Its Impacts On Encounters with Nature and Outdoor Adventure," 7th Annual Spokane Intercollegiate Research Conference, Spokane, WA, USA, April 25

2008 "Laboratory Scale Sand Separation of Dairy Manure using Column Diffuser," Student Undergraduate Research Experience Symposium, Potsdam, NY, USA, July 31

2008 "Gonzaga EWB Chapter: WATER in Benin Tackles Global Water Crisis." Engineers Without Borders – USA 2008 International Conference, Seattle, WA, USA, March 28-30

CAMPUS TALKS

2016 "Types of academic participation in STEM (in development)," ENSC 193: First-Year Seminar, Spokane, Washington, USA, September 06

2015 "Post-GU Experiences: A Guest Presentation," ENSC 100-02: Engineering Seminar, Spokane, Washington, USA, October 29

2015 "Vocation: The Place Where Your Deep Gladness Meets the World's Deep Needs," Comprehensive Leadership Program, Spokane, Washington, USA, September 23

2015 "Designing for life between buildings: Measuring the potential influence of urban design qualities on pedestrian activity," 2015 Faculty of Engineering Research Presentation Day, Glasgow, Scotland, UK, June 24

TEACHING EXPERIENCE

Gonzaga University

Air Pollution (Fall 2016)
Construction Materials Lab (Fall 2011)
Environmental Engineering (Fall 2015)
Environmental Engineering Lab (Spring 2012)
Infrastructure Design (Summer 2012)
Senior Design Project I (Fall 2011)
Senior Design Project II (Spring 2012)
Soil Mechanics (Fall 2011)
Statics (Spring 2012)
Sustainable Systems and Design (Spring 2012 & 2016; Fall 2016)

Clarkson University

Introduction to Environmental Engineering (Spring 2011), Teaching Assistant
Reinforced Concrete Design (Fall 2010), Teaching Assistant

RESEARCH EXPERIENCE

University of Strathclyde

2012-2015 Fulbright Postgraduate Research Scholar, Urban Design Studies Unit, Glasgow, Scotland, UK

Singapore University of Technology and Design (SUTD)

2013 Visiting Researcher, SUTD-MIT City Form Lab, Singapore, Singapore

Clarkson University

2009-2011 Research Assistant, Potsdam, NY, USA
2008 NSF REU Fellow, Potsdam, NY, USA

Gonzaga University

2010 Visiting Field Researcher, Chimfunshi & Zambezi, Zambia
2008 Visiting Field Researcher, Zambezi, Zambia

SERVICE TO PROFESSION

Reviewer, Urban Studies, 2013-

DEPARTMENTAL/UNIVERSITY SERVICE

Member, Faculty search committee, Gonzaga University, Department of Civil Engineering, 2011-2012
Student member, Faculty search committee, Gonzaga University, Department of Civil Engineering, 2007-2008

EXTRA TRAINING

GIS Essentials, Planetizen courses, Online. Sep.-Oct. 2014
Form-Based Codes 101e – That ABCs of Form-Based Codes, Form-Based Code Institute, Online, Nov. 2011-Jan. 2012
New York Summer Architecture Design Studio, Columbia University, New York, NY, USA, Jul.-Aug. 2011
Principles and Practices of New Urbanism, University of Miami, Online, Jan.-May 2010
West African Technology, Education, and Reciprocity Program, Gonzaga University, Porto Nova, Benin, Aug. 2007

COMMUNITY INVOLVEMENT/OUTREACH

Consultant, Ethiopia Reads

Mentor, Sutton Trust & Fulbright 1:1 Program
Reading Panelist, US-UK Fulbright Commission

MEDIA COVERAGE

2015 J. Evans-Cowley. (July 17). Tomorrow's Digital City Center: The Glasgow Agenda. Planetizen. Available from: http://www.planetizen.com/node/79525/tomorrows-digital-city-center-glasgow-agenda
2014 C. R. Wolfe. (April 2). The Bottom-Line Patterns of Urban Street Design. Huffington Post. Available from: http://www.huffingtonpost.com/charles-r-wolfe/honoring-underlying-patte_b_5071931.html
2014 S. Ferro. (March 31). Street Networks Are Twice the Size They Were Before Cars. Fast Company. Available from: http://www.fastcodesign.com/3028395/slicker-city/street-networks-are-twice-the-size-they-were-before-cars
2014 C. R. Wolfe. (March 20). The Underlying Patterns of Urban Street Design. Planetizen. Available from: http://www.planetizen.com/node/67905

RELATED PROFESSIONAL SKILLS

Professional Accreditations

2010- Congress for the New Urbanism – Accredited Member
2010- Leadership in Energy and Environmental Design Green Associate, GBCI#: 10340658
2009- Engineer in Training, State of Washington, License: 29774

Software

ArcGIS
QGIS
AutoCAD
SPSS
NVivo

NONACADEMIC WORK

2016 External Consultant, UN-Habitat, Urban Planning and Design Branch, Climate Change Planning Unit
2014-2015 External Consultant & Rapporteur, Urban Land Institute (ULI) & Glasgow Chamber of Commerce (GCC), Glasgow, Scotland, UK
2015 External Consultant & Rapporteur, UN-Habitat, Urban Planning and Design Branch, Climate Change Planning Unit
2014 External Consultant, ICLEI – Local Governments for Sustainability
2013-2014 United Nations Intern, UN-Habitat, Urban Planning and Design Branch, Climate Change Planning Unit, Nairobi, Kenya
2007 Civil Engineering Intern, South Main, Buena Vista, CO, USA

TEACHING AREAS

Environmental Science & Engineering
Atmospheric Chemistry & Physics
Cities & Climate Change
Urban Design

LANGUAGES

English, Fluent

PROFESSIONAL MEMBERSHIPS OR AFFILIATIONS

American Academy of Environmental Engineers and Scientists
American Society of Civil Engineers
Tau Beta Pi – Engineering Honors Society
Urban Climate Change Research Network
Urban Design Group
US Green Building Council
Congress for the New Urbanism

RELATED PUBLICATION

PUBLICATION

Article

Urban Studies

Urban Studies
2014, Vol. 51(16) 3383–3400

DOI: 10.1177/0042098013519833
usj.sagepub.com
SAGE

Alterations in scale: Patterns of change in main street networks across time and space

Sergio Porta
University of Strathclyde, UK

Ombretta Romice
University of Strathclyde, UK

J Alexander Maxwell
University of Strathclyde, UK

Peter Russell
University of Strathclyde, UK

Darren Baird
University of Strathclyde, UK

Abstract
This paper presents a morphological study of 100 main street networks from urban areas around the world. An expansion in the scale of main street networks was revealed using a unique heuristic visual method for identifying and measuring the lengths of main street segments from each of the study areas. Case studies were selected and grouped according to corresponding urban design paradigms, ranging from antiquity to present day. This research shows that the average lengths of main street segments from networks of historic (i.e. ancient, medieval, renaissance, baroque and industrial) and informal case studies are much smaller relative to those from networks of more contemporary case studies (i.e. Garden City, Radiant City and New Urbanism). This study provides empirical evidence in support of prior, observational claims suggesting a consistent pattern in the smaller scale of main street networks from traditional urban areas, termed the '400-metre rule'. Additionally, it makes the case for further empirical research into similarly recursive spatial patterns within other elements of urban form (i.e. plots, blocks, etc.) that, if discovered, could aid in future urban design efforts to help provide the framework for more 'human-scale' urban environments.

Corresponding author:
J Alexander Maxwell, University of Strathclyde, Architecture, 75 Montrose Street, Level 3, James Weir Building, Glasgow G1 1XJ, UK.
Email: john.maxwell@strath.ac.uk

Keywords
400-metre rule, main street network, main streets, urban morphology, urban theory

Received February 2013; accepted December 2013

Introduction

Cities are defined by a collection of both physical (e.g. streets, buildings and parks) and non-physical elements (e.g. history, culture and politics). Some of the physical features change slowly throughout time, while others are subject to more rapid transformations. This dynamic between various rates of change is vitally important in understanding how urban form is able to adapt to fluctuating economic, environmental and social circumstances throughout time (Caniggia and Maffei, 2001; Conzen, 1960; Moudon, 1989; Slater, 1990).

As one of the more permanent features of urban form, main street networks are vitally important. Main street networks, represented as intersecting systems of main streets that form unique main street segments (edges) and points of intersection (nodes), have been shown to share similar properties to those of other spatially complex networks such as power grids, mobile phone networks and neural networks (Barthélemy, 2011). Main street networks are also known to exert significant influence on people and their ability to navigate space (Hillier, 1996; Porta et al., 2010). Main streets have been found to remain central in the spatial organisation of urban areas throughout time across significant social, economic and environmental changes (Strano et al., 2012). Similarly, many (Anderson, 1986; Jacobs, 1961; Mehta and Bosson, 2010; Moughtin, 2003) have stated that careful concern should be given to the design of urban main street networks as dynamic vessels for human movement that are intimately linked throughout time to both physical and intangible elements of places.

According to Mehaffy et al. (2010), the pattern of intersecting main streets, prior to the advent of the automobile and the application of modern urban design paradigms, has followed a recurrent and consistent trend, termed the '400-metre rule'. According to this rule, urban areas comprised of quieter, mostly residential uses, also termed 'sanctuary areas' after Appleyard (1981), are bordered by main streets that intersect at intervals that seldom exceed 400 metres. Intersections occur at the junction of two or more streets, though not necessarily in the form of a rectilinear grid pattern. Main street networks connect local urban areas with their regional context and have constituted the commercial and service backbone of cities for many centuries, allowing non-residential uses to take advantage of more central locations at the local and regional scale. The scale of this spatial pattern, or 400-metre rule, reflects the limitations of pedestrian movements and the self-organising logic of social urban life prior to the advent of the automobile, highways systems and the application of professional urban design paradigms in the early 20th century.

Based on preliminary observations, Mehaffy et al. (2010) argue that significant alterations to the scale of contemporary main street networks, starting at the dawn of the 20th century, have been accompanied by a loss of a consistent spatial pattern and an expansion in the lengths of main street segments. These changes to urban form are influenced by several, interrelated factors including an increase in post-World War II housing demand, the rise of the automobile industry and federal highway systems (in the

Figure 1. Spatial distribution of case studies across 30 countries.

USA), the growth of middle-class consumers and changes in market preferences, and several other social and political factors, including the application of professional urban design paradigms. These paradigms include Ebenezer Howard's Garden City (Howard, 1902), Clarence Perry's Neighbourhood Unit (Perry, 1929), Le Corbusier's Radiant City (Le Corbusier, 1933), and continue with contemporary place-making and New Urbanism (Calthorpe, 2002; Congress for the New Urbanism, 2013; Duany et al., 2009; Farr, 2008).

In an effort to test the observational claims behind the 400-metre rule, this paper presents the morphological analysis of 100 diverse main street networks from different historic, geographical, social and economic systems using a unique heuristic visual method. The data gathered in this study offers empirical evidence in support of the 400-metre rule and makes the case for further empirical research into the structure of urban form and patterns linked to main street segments. This may reveal similar alterations in the urban fabric of cities corresponding to the physical application of urban design paradigms and other social factors.

Methodology

Selection of case studies

In order to test the 400-metre rule, measurements of main street segments of 100 case studies from 30 countries (Figure 1) were analysed to identify spatial patterns in the street network and if any alterations to this pattern occurred counter to the 400-metre rule. While this study is intended to represent an international distribution of cases, it is important to note that there exists a higher concentration of case studies from North America and Western Europe. This is a result of both the time constraints of this study and the bulk of the reference materials coming from the USA, UK and other Western European countries, where urban design is widely taught and researched.

Case studies were selected according to corresponding urban design paradigms (Table 1). Case studies were studied in their current state as reported by Google Earth (Google Inc., 2012) in the summer of 2010, and selected based on the following criteria: (1) each case study must be well researched and documented in published literature; and (2) each case study must still be universally recognised as being representative of one of

Table 1. List of case studies according to urban design paradigm grouping.

Study area location	Distance to capital city (m)	Population (people)	Date of origin (year)	Paradigm
Bologna, Italy	300	376,800	100–1 BCE	Ancient
Lucca, Italy	270	84,323	180 BCE	Ancient
Pavia, Italy	450	71,000	187 BCE	Ancient
Piacenza, Italy	411	101,325	218 BCE	Ancient
Pompei, Italy	210	20,000	800–701 BCE	Ancient
Verona, Italy	410	265,410	550 BCE	Ancient
Grammichele, Sicily, Italy	550	13,145	1693	Baroque
Karlsruhe, Germany	525	291,959	1715	Baroque
Noto, Sicily, Italy	600	23,816	1693	Baroque
Ragusa, Italy	586	72,836	1693	Baroque
Ciudad Guyana, Venezuela	520	940,477	1961	Garden City
Cumbernauld, UK	560	49,664	1955	Garden City
East Kilbride, UK	540	73,320	1947	Garden City
Farsta, Stockholm, Sweden	0	45,463	1957	Garden City
Glenrothes, UK	560	38,927	1948	Garden City
Greenbelt, MD, USA	20	21,465	1937	Garden City
Greendale, WI, USA	1020	14,405	1938	Garden City
Greenhills, OH, USA	647	4103	1930s	Garden City
Hilversum, The Netherlands	25	83,640	1950s	Garden City
Letchworth, UK	50	33,600	1903	Garden City
Lusaka, Zambia	0	3.1 M	1960	Garden City
Milton Keynes, UK	70	195,687	1967	Garden City
Navi Mumbai, India	1100	2.6 M	1972	Garden City
Radburn, NJ, USA	330	3100	1928	Garden City
Riverside, IL, USA	970	8895	1920s	Garden City
Seishin, Kobe, Japan	420	Unknown	1970s	Garden City
Tama, Tokyo, Japan	0	114,348	1971	Garden City
Tapiola, Finland	10	16,000	mid 1960s	Garden City
Vallingby, Sweden	10	25,000+	1954	Garden City
Welwyn, UK	30	3254	1920	Garden City
Barcelona, Spain	500	1.6 M	1859	Industrial
Boston, MA, USA	630	645,169	1882	Industrial
Calcutta, India	1300	5.1 M	1850	Industrial
Chicago, IL, USA	968	2.8 M	1871	Industrial
Manchester, UK	260	464,200	1853	Industrial
Merchant City, Glasgow, UK	550	3595	1700s	Industrial
Middlesbrough, UK	350	139,000	1830	Industrial
Milan, Italy	473	1.86 M	1861	Industrial
Paris, France	0	2.1 M	1852	Industrial
Philadelphia, PA, USA	190	1.5 M	1876	Industrial
Stockholm, Sweden	0	829,400	1897	Industrial
Badli, New Delhi, India	0	45,200	1961	Informal Settlement
Bario, Caracas, Venezuela	0	Unknown	1940s	Informal Settlement

(continued)

Table 1. (Continued)

Study area location	Distance to capital city (m)	Population (people)	Date of origin (year)	Paradigm
Cemetery Squatters, Port au Prince, Haiti	0	100,000	1960	Informal Settlement
Dharavi, Mumbai, India	1140	1 M	1930	Informal Settlement
Hanna Nassif, Dar-es-Salaam, Tanzania	388	23,000	1960s	Informal Settlement
Kakrail, Dhaka, Bangladesh	0	120,000	1980	Informal Settlement
Khayelitsha, Cape Town	1300	406,779	1957	Informal Settlement
Kibera, Nairobi, Kenya	0	1 M+	1960s	Informal Settlement
Kranidi, Greece	100	10,000	1970s	Informal Settlement
Kricak, Yogyakarta, Indonesia	427	300,000	1950	Informal Settlement
Lagos, Lagos Island, Nigeria	530	209,000	1963	Informal Settlement
Las Colinas, Bogota, Columbia	0	10,000	1960	Informal Settlement
Lima, Hill Squatters, Peru	0	Unknown	1960s	Informal Settlement
Mafalala, Maputo, Mozambique	0	22,000	pre 1975	Informal Settlement
Orangi Town, Karachi, Pakistan	1140	1.5 M	1965	Informal Settlement
Rocinha, Rio De Janeiro, Brazil	930	250,000	1970s	Informal Settlement
Rufisque, Dakar, Senegal,	0	179,797	1987	Informal Settlement
Tondo, Manila, Philippines	0	630,000	900	Informal Settlement
Urban Village, Shenzhen, China	1930	70,000	1980s	Informal Settlement
West Point, Monrovia, Liberia	0	75,000	1980s	Informal Settlement
Bremen, Germany	316	547,645	1032	Medieval
Lubeck, Germany	235	210,892	1143	Medieval
Nuremberg, Germany	380	503,600	1050	Medieval
Tripoli, Libya	0	1.06 M	1510	Medieval
Verdun, France	220	19,624	1374	Medieval
Vienna, Austria	0	1.7 M	1440	Medieval
Brentwood CA, USA	3700	4200	2005	New Urbanism
Celebration FL, USA	1200	11,860	1990	New Urbanism
Communications Hill, Sacramento, CA, USA	3800	2800 units	2010	New Urbanism
Kentlands, Gaithersburg, MD, USA	30	2000 homes	1990	New Urbanism
Laguna West, Sacramento, CA, USA	3800	8414	1991	New Urbanism
Orenco Station, Portland OR, USA	3700	>46,124	1997	New Urbanism
Poundbury, UK	186	6000	1993	New Urbanism
Rosemary Beach, FL, USA	1250	500 homes	1995	New Urbanism

(continued)

Table 1. (Continued)

Study area location	Distance to capital city (m)	Population (people)	Date of origin (year)	Paradigm
Seaside, FL, USA	1250	2000	1979	New Urbanism
Windsor, Vero Beach, FL, USA	1286	350 homes	1989	New Urbanism
Akademgorodok, Novosibirsk, Russia	2800	65,000	1950s	Radiant City
Barbican Estate, London, UK	0	4000	1969	Radiant City
Blue Area, Islamabad, Pakistan	0	530,000	1958	Radiant City
Brasilia, F.D. Brazil	0	2.6 M	1960	Radiant City
Cabrini Green, Chicago, IL, USA	968	15,000	1942–2008	Radiant City
Chandigarh, India	230	900,000	1953	Radiant City
Co-op city, New York, NY, USA	330	55,000+	1973	Radiant City
Cumbernauld, UK	560	49,664	1956	Radiant City
Drumul Taberei, Bucharest, Romania	0	63,000+	1974	Radiant City
La Grande Borne, Grigny, France	22	26,790	1980s	Radiant City
Le Mirail, Toulouse, France	580	27,500	1968	Radiant City
Marzahn, Berlin, Germany	0	102,398	1977	Radiant City
Milton Keynes, UK	70	195,687	1967	Radiant City
Pendrecht, Rotterdam, The Netherlands	60	12,400	1953	Radiant City
Pruitt-Igoe, St. Louis, MO, USA	1146	2740 units	1954–1972	Radiant City
Regent Park, Toronto, ON, Canada	352	10,385	1940s	Radiant City
Roehampton, London, UK	0	13,000+	1950s	Radiant City
Stuyvesant Town, New York City, NY USA	330	25,000+	1947	Radiant City
The Grand Ensemble of Sarcelles, Paris, France	0	60,196	1960s	Radiant City
Tsukuba Science City, Japan	50	207,000	1960s	Radiant City
Freudenstadt, Germany	575	23,690	1599	Renaissance
Neuf Brisach, France	390	2219	1697	Renaissance
Palmanova, Italy	450	5406	1593	Renaissance

the paradigms listed in Table 1 according to available literature. Historic cases (30) represent main street networks that correspond to ancient (6), medieval (6), renaissance (3), baroque (4) and industrial (11) paradigms, while contemporary cases represent those selected from the Garden City (20), Radiant City (20) and New Urbanism (10) models.

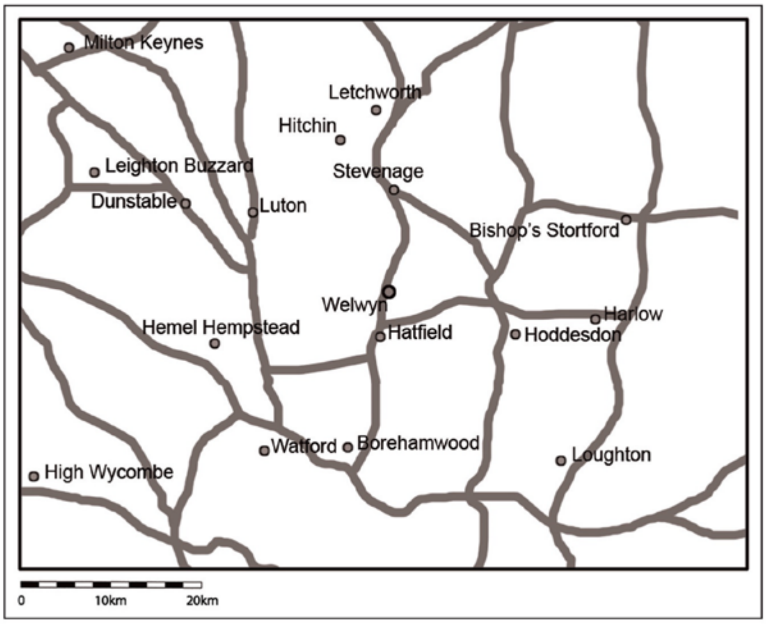


Figure 2. Regional map for Welwyn, UK.

Informal settlements were also examined as an exploding phenomenon that cannot be aligned with any of the paradigms of urban design mentioned above. Informal settlements are urban areas often characterised as poor places lacking access to clean water, safe sanitation, secure land tenure or durable housing. The form and development of informal settlements, like the historic cases, lack influence from contemporary, professional urban design theories.

Mapping

Mapping of urban street networks was conducted using Google Earth web-based, imagery software (Google Inc., 2012), historic maps as needed, and Adobe Creative Suite 5 graphic design applications. Google Earth has been recognised as a valuable urban design tool for spatial education (Patterson, 2007) and urban analysis (Clarke et al., 2010; Farman, 2010; Sheppard and Cizek, 2009). For the purposes of this study, Google Earth was used to generate three maps of varying scales:

(1) The Regional Map – a simple diagram (Figure 2) used to map the settlement within its regional context. This map includes the location of the study area, neighbouring towns and capital cities, regional roads and geographical boundaries between land masses and water bodies.
(2) The Main Urban Street Network Map – a more detailed map (Figure 3) of the urban street network for the study area. This map shows all main streets and railway lines connecting the study area with the surrounding region, identifies nodes of intersection between

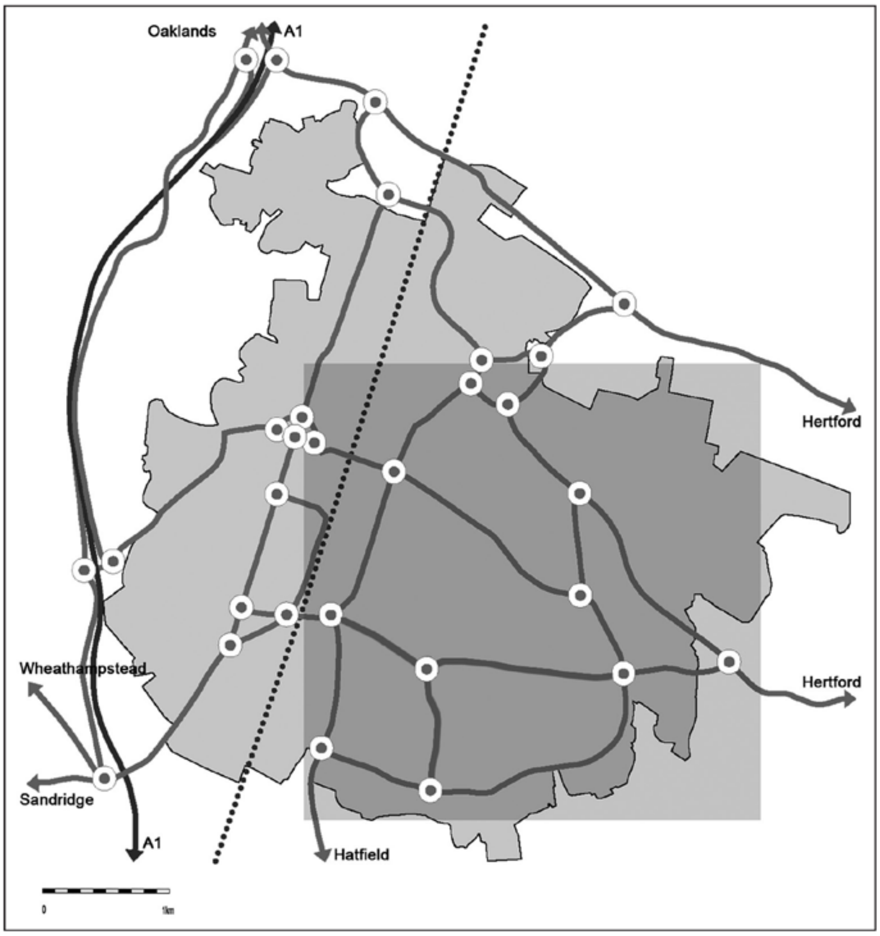


Figure 3. Main urban street network map for Welwyn, UK.

main streets, and locates sanctuary areas within the urban street network.

(3) The Sanctuary Area(s) Map – a scaled, satellite map of the sanctuary areas taken from the urban street network map at an altitude of ≤800 m in order to generate a high resolution sanctuary areas map (Figure 4). This map displays all main streets and nodes of intersection forming and connecting sanctuary areas within the study area. Local streets, found only within singular sanctuary areas, are not highlighted in the map and instead are left on the layer of the background satellite image. Overall, these maps are used to measure all main street segments along the perimeters of sanctuary areas in order to compare segment lengths between all of the case studies.

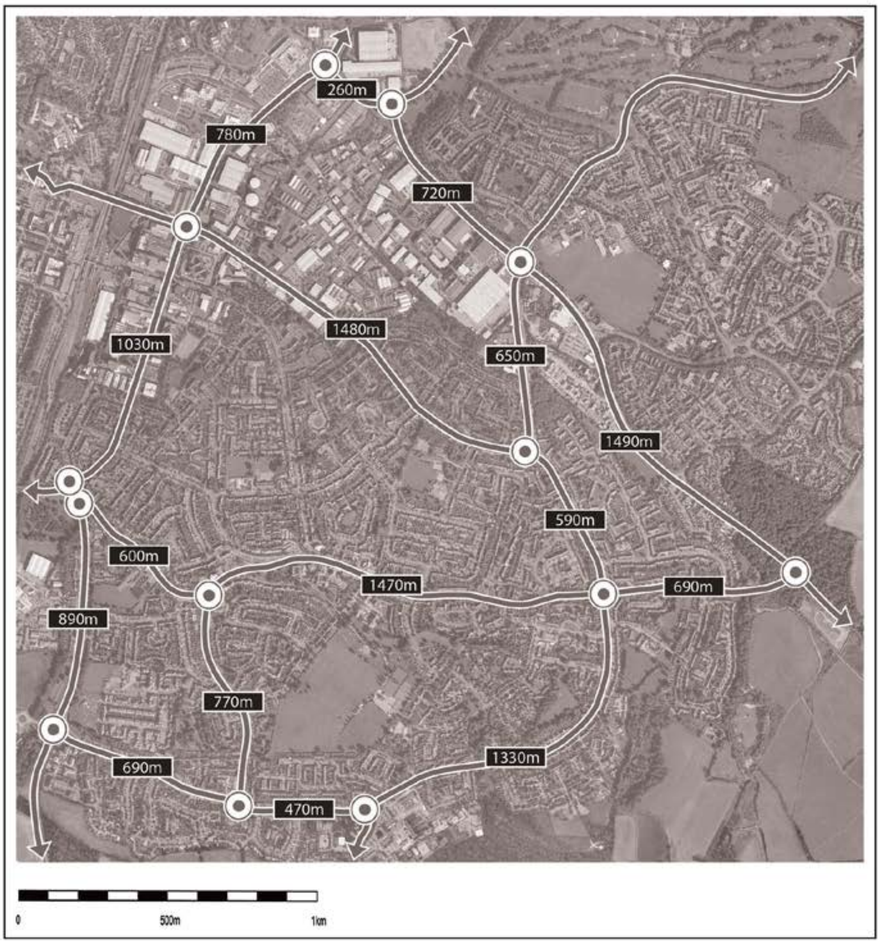


Figure 4. Sanctuary area(s) map for Welwyn, UK.

It is worth noting that the selection of sanctuary areas was done in a subjective manner in order to get good representations of the urban design paradigms to which the main street network of the case belonged.

Visual identification of main streets

In order to identify the main streets and nodes within the sanctuary area for each case study, the following visual, heuristic approach was applied.

(1) Using Google Earth, satellite images (with only the *Borders and Labels* & *Roads* layers) and historic maps (as needed) of the study area at the scale of the Regional and Urban Street Network maps, select as main streets those roads that can be easily identified

as connecting the study area to other towns or cities. In Figures 2 and 3, the main streets are those roads that serve as the main connections between the towns of Hertford, Hatfield, Sandridge, Oaklands and Wheathampstead.

(2) When a main street splits into two or more directions, use visual clues such as number of lanes, width of roads, and street names (e.g. High Street, M8, county road, etc.) to establish a hierarchy of roads and determine the continuous path of the main street.
(3) Additionally, roads that traverse or serve as a connection across significant barriers in the street network (i.e. railway lines, motorways, rivers, etc.) are selected as main streets.
(4) Nodes mark the intersection of two or more main streets and serve as the endpoints to the main street segments. Thus, main streets segments are defined as sections of main streets that originate and end at nodes.
(5) In the case of squares and roundabouts, main streets can also be identified as those streets that connect the endpoint nodes of other main street segments coming into the square or roundabout.

The heuristic approach is purely visual and based on information that refers solely to geographical features and underlining considerations of connectivity of the street network. Other elements including traffic, land use or demographics were not mapped or taken into consideration during this study.

Method validation

The reliability of the visual identification method was tested by conducting an exercise with a group of fourth-year undergraduate architecture students. Students were selected based on their unfamiliarity with the methods used in this study. During the exercise, each student was given a computer with Google Earth, a marker and a sanctuary areas map from a set of ten study areas randomly selected to cover each of the urban design paradigm groupings. For example, referencing Table 2, five students were given identical maps of the Palmanova study area, while six students were given identical maps of the Greendale study area and so forth. Given an hour, the students were then instructed to follow the visual method described above to identify all main streets on the corresponding sanctuary areas map using a bold marker to mark all nodes and main street segments. These results were then compared with the main street segments identified by the authors in order to determine the number of similarly identified main streets. These results are included in Table 2 below.

Overall, a total of 51 samples were collected from 25 students and 860 main street segments were identified. The percentage of similarly identified main streets across all of the case studies used in this experiment was 89%. When the samples included fewer main streets, the results from the student more closely matched those of the authors.

Statistical methods

Descriptive statistics were calculated on the main street segment lengths for each of the 100 case studies using SigmaPlot 10 (Systat Software Inc., 2006). These statistics were then compiled to identify the means, standard deviations, medians, minimum values, maximum values and outliers for each period in the history of urban design and represented using a Tukey vertical box plot (Tukey, 1977) in order to make non-parametric comparisons in the results between each period in the history of urban design and determine the validity of the 400-metre rule (Figure 5).

Table 2. Results from visual analysis experiment.

	Historical		Garden City		Radiant City		New Urbanism		Informal Settlements	
	Palmanova (A)	Lubeck (B)	Letchworth (A)	Greendale (B)	Chandigarh (A)	Drumul Taberel (B)	Kentlands (A)	Poundbury (B)	Port au Prince (A)	Bogota (B)
Number of samples	5	4	6	6	6	6	4	5	5	4
Number of main streets per sample	6	28	27	19	8	14	23	9	17	22
Number of main streets	30	112	162	114	48	84	92	45	85	88
Percentage of similarly identified main streets	100%	83%	87%	94%	100%	95%	83%	100%	86%	82%

Results

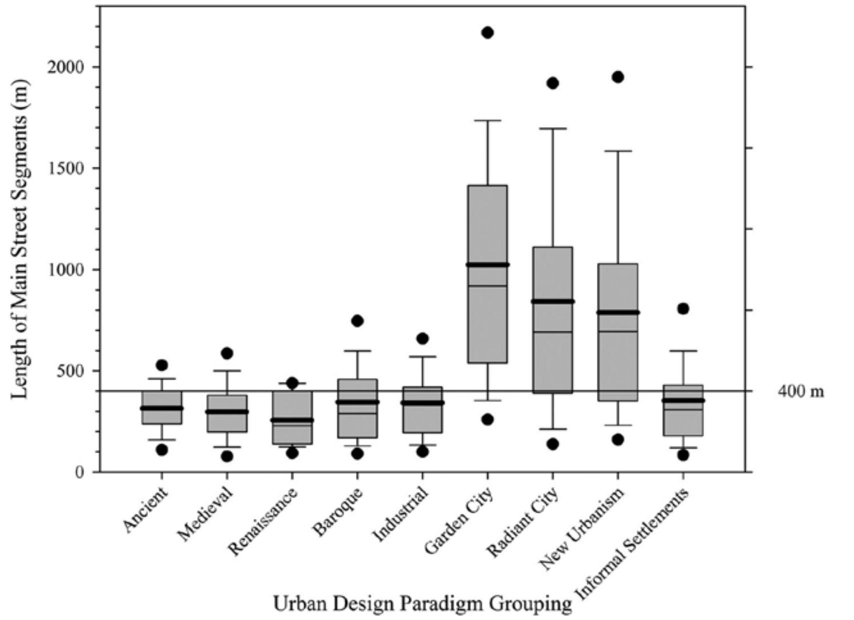
Both the mean and median can be used as measures of the central tendency of the sample; however, while the mean values are primarily discussed below, it is important to represent the median values, as the mean values can be affected by outliers as seen in the Garden City, Radiant City and New Urbanism cases. In these cases, the median can be used as a better measure of the midpoint of the sample. This graph (Figure 5) also shows the 400-metre mark to allow for easier comparisons to be made in relation to the 400-metre rule.

The average values for main streets from ancient, medieval, renaissance, baroque, industrial and informal settlement case studies are 315 m ± 118 m, 299 m ± 146 m, 257 m ± 127 m, 347 m ± 243 m, 343 m ± 185 m and 354 m ± 258 m, respectively. This suggests that most main streets from historic and informal settlement cases follow the 400-metre rule. However, the mean values for main streets from Garden City, Radiant City and New Urbanism case studies vary greatly (1026 m ± 638 m, 843 m ± 714 m and 788 m ± 541 m, respectively) and are well beyond the limit set by the 400-metre rule. This suggests that a change has occurred with the advent of professional approaches to modern and postmodern urban design, the spread of the automobile and other social forces mentioned above, causing the scale of urban street networks to be altered.

Discussion

Historic cities

Since their inception, cities have been shaped by the environmental, economic and social aims of communities (Hiorns, 1956; Morris, 1994). Historic cities, formed in the absence of automobiles, were designed according to practical principles with street networks that



The bold line marks the arithmetic mean or average, the fine line represents the median, the box represents the range from 25th to the 75th percentiles, the whiskers (error bars) represent the 10th and 90th percentiles, and the dots represent the 5% & 95% outliers of each grouping.

Figure 5. Lengths of main street segments by urban design paradigm grouping.

were limited in scale, allowing for pedestrians to walk to essential services (Newman and Kenworthy, 1999). Cities were often centred on a square, market, castle or other civic structure with main streets leading outward from the centre in radial, rectilinear or sometimes unplanned patterns towards the edge, marked by walls or other significant barriers (Hiorns, 1956; Morris, 1994). These principles of design allowed for cities to evolve throughout time, adapting to meet the changing needs of society and adjust to new advances in technology.

In this study, for the 30 cases analysed between the periods of antiquity and the industrial revolution, the average main street segment was 331 m ± 179 m, indicating a pattern of urban form based on a close-grain framework of main street segments. The 95% outliers from the baroque and industrial periods came from unique main streets within the sanctuary areas of Karlsruhe, Germany and Calcutta, India, respectively. In Karlsruhe, 29 individual main streets were identified, yielding an average segment length of 546 m ± 325 m. In Calcutta, 87 main streets were analysed, yielding an average segment length of 462 m ± 236 m. These deviations, while significant, do not impact the relatively small variation in average main street lengths between all cases from historic periods (331 m ± 179 m), and the mean and standard deviation for both Karlsruhe and Calcutta still place them within the range of the 400-metre rule. Overall, the evidence from these historic cases indicates a consistent pattern in the length of main street segments that follows the 400-metre rule.

Responses to industrialisation

The industrialisation of cities built on a framework of close-grain street networks during the late 18th and early 19th centuries resulted in overcrowded, polluted and unsanitary living conditions (Hiorns, 1956; Morris, 1994). As a consequence, by the late 19th and early 20th centuries, several new theories of urban design were developed in an attempt to address these issues. This ushered in a new era in the history of urban design focused on the generation of healthier urban environments based on several important principles: improved efficiency through the use of modern transportation systems and new building materials, separation of industry and other land uses to promote public health and the increased interaction of diverse demographics through the better use of public open space. Ebenezer Howard's Garden City (Howard, 1902) and Le Corbusier's Radiant City (Le Corbusier, 1933) were two of the most prominent of these new approaches to urban design based on the abovementioned theoretical principles. It is also important to understand that they were realised as expressions 'sometimes, to be sure, almost unrecognisably distorted – of the ideas' (Hall, 2003).

Around the turn of the century, Howard proposed a relief to the urban conditions of industrial cities by envisioning cities that would provide access to country living. In his Garden City model, Howard designed detailed diagrams of concentric garden cities intended to fit on 600 acres of land and house 30,000 people, with an additional 2000 living in the surrounding agrarian land. Boulevards, avenues and roads separated residents from industry, which was placed on the edge of the cities, neighbouring farms and forestlands. A series of greenbelts, mass transit systems and motorways were planned to provide connection between neighbouring garden cities and a central city of 50,000 people. Theoretically, each Garden City was designed to provide ample housing, jobs, manufacturing and access to open space (Howard, 1902).

While Howard's Garden City model served as a logical alternative to the plights of urban dwellers, it was never fully realised in its original form. When the theoretical principles of the Garden City model were applied, garden cities were sometimes transformed into diluted forms, conventionally known as garden suburbs, the kind analysed in the case studies from the Garden City grouping. Some of these cases include Ciudad Guyana, Venezuela, Greendale, USA and Letchworth, UK. These garden suburbs, where activity is centred, industry is separated from residential areas and low-density residential development is clustered together on the edges, while following Howard's principles, gave rise to the physical manifestation now known as sprawl (Ward, 1992).

In the 30 cases studied from the Garden City period, the average main street segments measured 1026 m ± 638 m, more than double the 331 m ± 179 m of the 30 historic case studies. This increase in segment length and the relatively high variability in the results indicate an alteration in the scale of the urban street network counter to the 400-metre rule and the departure from traditional spatial patterns.

Like Howard, Le Corbusier also sought to improve public health, increase efficiency and reconnect urban living with nature through his Radiant City model. Le Corbusier's Radiant City was based on the theoretical arrangement of high-density, residential skyscrapers connected through a series of aboveground highways on a rectilinear grid (Le Corbusier, 1933). In this model, traditional main streets became obsolete, and were replaced with highways elevated above the ground. This left the ground plane to be given over to open space that could be used by pedestrians. Le Corbusier embraced the technological advances of the early 20th century, principally the use of the private automobile as means of transportation for the new masses of middle-class urbanities in the machine-age, while rejecting appeals by others, including Camillo Sitte (Sitte, 1889), to reinvestigate traditional forms of urban design as a way to balance the benefits of modern technology with the essential physical characteristics of historic urban forms (Le Corbusier, 1929).

Le Corbusier was able to fully realise one Radiant City, Chandigarh, India. Like Howard, his model was immensely influential in informing, often literally and explicitly, innumerable others that have been constructed according to similar principles. These are represented in the 20 cases selected from the Radiant City grouping. These cases include Brasilia (Brazil), Regent Park, Toronto (Canada), and La Grande Borne, Grigny (France). While originally intended to be arranged on a 400-metre framework, when constructed, Le Corbusier's radiant cities resulted in reformed grids of superblocks with main street segments measuring up to 1065 m ± 305 m as is the case in Chandigarh. The average main street lengths for all of the cases from the Radiant City period measured 843 m ± 714 m, more than double that of historic main street segments. This again shows an alteration in scale and loss of consistent pattern within the urban street network.

Overall, these two theories were based on principles that were designed to provide access to open space, set urban growth boundaries and deliver dense, transit-oriented communities. However, when fully realised, these theoretical approaches contributed to unintended consequences that include low-rise, residential sprawl, spatial and social segregation, decaying services and commerce, declining public life and automobile dependence.

Response to the physical manifestations of modernist principles

Around the same time that Le Corbusier developed his principles for the design of the contemporary city, Clarence Perry suggested a new way of organising and improving upon the problems of industrial cities called the Neighbourhood Unit. Neighbourhood Units were focused on principles of walkability and were organised around significant, community structures, namely schools or churches, which would be accessible by pedestrians living no more than a 400-metre radius away from the centre (Perry, 1929). Main streets formed the perimeter of each neighbourhood and were spaced in segments roughly 800 m apart, the same scale as those evident in the Garden City and Radiant City paradigms. Theoretically, this was meant to ensure that a sense of community was developed and that main streets were used to form the edges of neighbourhood sanctuary areas (Ben-Joseph, 2005).

In response to the separation of land uses and sprawling designs resulting from the applications of the modernist principles mentioned above, New Urbanism was developed as a way to refocus urban design on creating walkable, mixed-use neighbourhoods built on the principles of Perry's Neighbourhood Unit (Congress for the New Urbanism, 2013). Started around the end of the 20th century, New Urbanism focuses on creating developments based on a 400-metre radius where essential services are located within a 400-metre walk of the neighbourhood centre.

In the 10 New Urbanism cases studied, the average length of main street segments was 788 m ± 541 m. Cases from this period include the well-known developments of Seaside, USA, Celebration, USA and Orenco Station, USA. These results reflect the 800 m main street network that is a physical manifestation of the 400-metre radius of the Perry's Neighbourhood Unit. Like the cases from the Garden City and Radiant City period, the New Urbanism cases also represent a clear alteration in the scale of the main street pattern when compared with those developed before the application of professional theories in urban design.

Informal settlements

Interestingly, informal settlements represent similar patterns to those of historic urban street networks. The average main street segment measured 354 m ± 258 m for the 20 cases studied from this period, which is similar to the 331 m ± 179 m average found in 30 cases from historic cities. Cases from this period included Badli, New Dehli (India), Kibera, Nairobi (Kenya) and Rocinha, Rio De Janeiro (Brazil). According to these results, in the absence of theoretical principles of urban design, human settlements have tended to organise themselves according to the 400-metre rule. This suggests that informal settlements can serve as contemporary examples of the self-organising logic that was present in the patterns of historic cities.

Learning from the past: Towards urban sustainability

The scope of this paper is not to resort to the simplistic notion that historic cities are spontaneous and thus good, as opposed to contemporary cities that are planned and thus bad. Instead, the focus of this study is to bring new evidence in support of the disciplinary search for sustainable forms of urban design for the contemporary age. In most cases, historic cities developed over time as a result of both spontaneous and planned efforts, similar to what can be observed in contemporary informal settlements, which are often developed by non-institutional, sometimes illegal, local forms of authority.

With the increasing concerns over limited economic and environmental resources growing more acute at the turn of the century, urban design practitioners have become increasingly interested in the diverse, close-grain street networks of historic cities as a way to identify the essential characteristics of urban frameworks that provide for sustainability (Department of the Environment, Transport and the Regions (DETR) & Commission for Architecture and the Built Environment (CABE), 2000; Jones et al., 2007; Llewelyn Davies Yeang, 2000; Tarbatt, 2012). Some of these characteristics include the ability of close-grain street networks to encourage alternative modes of transportation, provide for well-connected, critical masses of customers to support local businesses, facilitate inclusion of diverse social groups in public places and create safe and attractive places for people to visit and live (Jones et al., 2007). Within the past several decades, New Urbanism and Place Making have been developed as two related approaches based on these same principles; however, this research shows that when these principles become fully realised into physical urban forms, they share the same alteration in the scale of main street networks as other post-industrial, modernist developments. This alteration in scale has become a structural component of contemporary urban landscapes with impacts to the way in which cities function. By identifying consistent patterns within the forms of more resilient cities, practitioners will be better equiped to make design decisions based on sound empirical evidence of what frameworks work throughout time and allow for progressive adaptability as changing populations continue to inhabit today's cities.

Conclusion

While this research is limited by the current sample size, it does provide initial evidence suggesting that main streets networks in historic cities have predominantly followed the 400-metre rule. This research also suggests that since the advent and application of professional modern and postmodern urban design theories at the dawn of the 20th century, the distance between main streets in cities has roughly doubled. Therefore we assert that an alteration in scale has occurred over time in coincidence with the establishment of modern and postmodern urban design paradigms. However, the alteration in scale does not appear in contemporary cities, which have developed in the absence of more formal planning and design (i.e. in informal settlements).

Explanations for the observations above may vary, and the causal role of the historic emergence of the automobile should be taken into consideration as well as other significant social and economic changes that have occurred in step with the establishment of urban design paradigms. However, all cities examined in this paper are contemporary cities and therefore they all have cars. But, only those built after the rise of the automobile and modern/postmodern urban design paradigms had been planned for the car by incorporating the neighbourhood unit and other automobile-oriented designs. Therefore, our conclusion is that the contribution of urban design models to the unsustainable, car-dominated city of today has been, and continues to be, of crucial and indeed generally underestimated importance. This conclusion is further supported by the final observation that contemporary cities, when not formally planned, do not exhibit signs of this alteration in scale.

This important discovery requires further research and has the potential to influence the future efforts of urban designers as they attempt to design today's sustainable cities, capable of reconciling the difference in timescales between the time required for urban places to evolve and the time these places are inhabited. The sudden increase in the scale of the main street network could imply a similar jump in the scale of other related sub-structures of urban form (e.g. plots, blocks, etc.). If this were the case, further study of these urban elements could offer an insight into different degrees of adaptability between places and uses over time and should prompt further research into more time-sensitive design.

The United Nation's (UN) 2009 report on global urbanisation prospects predicted that the global urban population will grow from slightly over 50% of the total population today to 70% by 2050, with developing regions contributing to the majority of this growth (UN-Habitat, 2009). The magnitude of this reality is such that the cost of remediating planning and design inadequacies will likely be too great to bear from an economic, social and environmental point of view. Another UN report also suggests that the majority of urban growth is to take place in smaller settlements, of less than 500,000 inhabitants, often lacking strong institutional frameworks to enforce and implement development which is socially and environmentally sustainable (UN-Habitat, 2011). Far from advocating a no-planning approach, which would naively fail to address the nature of contemporary urban market, this paper states that there is no better time than now to identify and employ well-informed design principles to guide this development. This is rather a call for better urban design and planning, an evolved and more responsive discipline which would aim at the generation of 'a built-up area that keeps adapting and transforming itself in unplanned neighbourhoods' (Panerai et al., 2004: 159).

This paper serves as a call for further research into the essential logic and principles of what generates a more adaptable, hence resilient, urban fabric. This essential logic has to do with urban morphology: by better understanding the critical relationships between urban streets and plots, urban designers can begin to repair and develop more adaptable urban tissues, capable of adjusting to changing demographics, economies and cultures over time.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

Anderson S (ed.) (1986) *On Streets*. London: MIT Press.

Appleyard D (1981) *Livable Streets*. London: University of California Press, Ltd.

Barthélemy M (2011) Spatial networks. *Physics Reports* 499(1): 1–101.

Ben-Joseph E (2005) *The Code of The City: Standards and The Hidden Language of Place Making*. London: MIT Press.

Calthorpe P (2002) *The Urban Network: A New Framework for Growth*. Available at: http://www.calthorpe.com/publications/urban-network-new-framework-growth, p. 6.

Caniggia G and Maffei GL (2001) *Architectural Composition and Building Typology: Interpreting Basic Building* (Fraser SJ, trans.). Florence: Alinea Editrice.

Clarke P, Ailshire J, Melendez R, et al. (2010) Using Google Earth to conduct a neighborhood audit: Reliability of a virtual audit instrument. *Health & Place* 16(6): 1224–1229.

Congress for the New Urbanism (2013) *Charter of the New Urbanism* (Talen E, ed.). London: McGraw Hill Education, LLC.

Conzen MRG (1960) Alnwick, Northumberland: A study in town-plan analysis. *Transactions and Papers (Institute of British Geographers)* 27: 122. Available at: http://www.jstor.org/stable/621094.

Department of the Environment, Transport and the Regions (DETR) & Commission for Architecture and the Built Environment (CABE) (2000) *By Design/Urban Design in the Planning System: Towards Better Practice*. London: DETR and CABE.

Duany A, Speck J and Lydon M (2009) *The Smart Growth Manual*. London: McGraw-Hill Professional.

Farman J (2010) Mapping the digital empire: Google Earth and the process of postmodern cartography. *New Media & Society* 12(6): 869–888.

Farr D (2008) *Sustainable Urbanism: Urban Design With Nature*. Hoboken, NJ: John Wiley & Sons, Inc.

Google Inc. (2012) *Google Earth, ver. 7.0*. Available at: http://www.google.com/earth/.

Hall P (2003) Cities of imagination. In: Hall P (ed.) *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the Twentieth Century*. Third Edition. Oxford: Blackwell Publishing, pp. 6–7.

Hillier B (1996) Cities as movement economies. *Urban Design International* 1: 41–60.

Hiorns FR (1956) *Town-Building in History: An Outline Review of Conditions, Influences, Ideas, and Methods Affecting 'Planned' Towns Through Five Thousand Years*. London: G.G. Harrap & Company Limited.

Howard E (1902) *Garden Cities of To-Morrow*. London: S. Sonnenschein & Co., Ltd.

Jacobs J (1961). *The Death and Life of Great American Cities*. New York: Random House.

Jones P, Roberts M and Morris L (2007). *Rediscovering Mixed-use Streets: The Contribution of Local High Streets to Sustainable Communities*. Bristol: Policy Press in association with the Joseph Rowntree Foundation.

Le Corbusier (1929) *The City of To-morrow and Its Planning* (translated by Frederick Etchells from Urbanisme: 8th edition). London: John Rodher.

Le Corbusier (1933) *La Ville Radieuse (The Radiant City)* (1967 Reprint edition). London: Faber.

Llewelyn Davies Yeang (2000) *Urban Design Compendium*. London: English Partnerships.

Mehaffy M, Porta S, Rofè Y, et al. (2010). Urban nuclei and the geometry of streets: The 'emergent neighborhoods' model. *Urban Design International* 15(1): 22–46.

Mehta V and Bosson JK (2010) Third places and the social life of streets. *Environment and Behavior* 42(6): 779–805.

Morris AEJ (1994) *History of Urban Form: Before the Industrial Revolutions*. Essex: Pearson Education Limited.

Moudon AV (1989) *Built for Change: Neighborhood Architecture in San Francisco*. London: MIT Press.

Moughtin C (2003) *Urban Design: Street and Square*. Oxford: Architectural Press.

Newman P and Kenworthy J (1999). *Sustainability and Cities: Overcoming Automobile Dependence*. Washington, DC: Island Press.

Panerai P, Castex J, Depaule JC, et al. (2004) *Urban Forms: The Death and Life of The Urban Block*. Oxford: Architectural Press.

Patterson TC (2007) Google Earth as a (not just) geography education tool. *Journal of Geography* 106(4): 145–152.

Perry C (1929) The Neighborhood Unit: A scheme of arrangement for the family life community. In: *Regional Plan of New York and Its Environs, Volume VII*. New York: Arno Press, p. 119.

Porta S, Latora V and Strano E (2010) Networks in urban design. Six years of research in multiple centrality assessment. In: Estrada E, Fox M and Higham DJ, et al. (eds) *Network Science*. London: Springer, pp. 107–129.

Sheppard SRJ and Cizek P (2009) The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation. *Journal of Environmental Management* 90(6): 2102–2117.

Sitte C (1889) *Der Städtebau nach seinen künstlerischen Grundsätzen (City Planning According to Artistic Principles)*. Transl. by George R Collins and Christiane Crasemann Collins. London: Phaidon Press.

Slater TR (ed.) (1990) *The Built Form of Western Cities: Essays for M.R.G. Conzen on the Occasion of his Eightieth Birthday*. Leicester: Leicester University Press.

Strano E, Nicosia V, Latora V, et al. (2012) Elementary processes governing the evolution of road networks. *Scientific Reports* 2(296): DOI: 10.1038/srep00296.

Systat Software Inc. (2006) *Sigma Plot, ver. 10*. Available at: http://www.sigmaplot.com/products/sigmaplot/sigmaplot-details.php.

Tarbatt J (2012) *The Plot | Designing Diversity in the Built Environment: A Manual for Architects and Urban Designers*. London: RIBA Publishing.

Tukey JW (1977) *Exploratory Data Analysis*. Reading, MA: Addison-Wesley.

UN-Habitat (2009) *Global Report on Human Settlements 2009: Planning Sustainable Cities*. London: Earthscan Ltd.

UN-Habitat (2011) *Global Report on Human Settlements 2011: Cities and Climate Change*. London: Earthscan Ltd.

Ward SV (1992) *The Garden City: Past, Present, and Future*. Oxford: Spon Press.