THE AUTOMATED CREATION OF PEDESTRIAN ROUTE DESCRIPTIONS

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Doctor of Philosophy

The University of Edinburgh

2013

Abstract

Providing unambiguous, succinct descriptions of routes for pedestrians to follow is very challenging. Route descriptions vary according to many things, such as route length and complexity, availability of easily identifiable landmarks, and personal preferences. It is well known that the inclusion of a variety of landmarks facilitates route following – either at key decision points, or as a confirmatory cue. Many of the existing solutions, however, behave like car navigation systems and do not include references to such landmarks. The broader ambition of this research is the automatic generation of route descriptions that cater specifically to the needs of the pedestrian. More specifically this research describes empirical evidence gathered to identify the information requirements for an automated pedestrian navigation system. The results of three experiments helped to identify the criteria that govern the relative saliency of features of interest within an urban environment. There are a large variety of features of interest (together with their descriptions) that can be used as directional aids within route descriptions (for example buildings, statues, monuments, hills, and roads). A set of variables were developed in order to measure the saliency of the different classes of features. The experiments revealed that the most important measures of saliency included name, size, age, and colour. This empirical work formed the basis of the development of a pedestrian navigation system that incorporated the automatic identification of features of interest using the City of Edinburgh as the study area. Additionally the system supported the calculation of the saliency of a feature of interest, the development of an intervisibility model for the route to be navigated to determine the best feature of interest to use at each decision point along the route. Finally, the pedestrian navigation system was evaluated against route descriptions gathered from a random set of individuals to see how efficiently the system reflected the more natural and richer route description that people typically generate. This work shows that modelling features of interest is the key to the automatic generation of route descriptions that can be readily understood and followed by pedestrians.

Statement of Originality

I declare that the work contained in this thesis, including text, figures, and tables, represents my own work, except where specifically stated. This work contains no material that has been accepted for the award of any other degree or diploma in any university or tertiary institution.

Signed

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22 February 2013

Acknowledgements

I would like to express my thanks to Dr William Mackaness and Bruce Gittings for their supervision, guidance, comments, and suggestions throughout the research.

The research into the cognitive map and its interaction with navigation was carried out during an internship with Horizon Digital Economy Research at the University of Nottingham. Thank you to Jeremy Morley and Dr Svenja Adolphs who helped shape this work.

Many thanks to the participants who agreed to take part in the experiments. Their contributions were an invaluable part of this research.

To everyone at Forth Valley GIS, thank you all very much for being incredibly supportive and understanding during this past year.

Thank you to everyone within the Institute of Geography, especially Iain Cameron, Gemma Cassells, Omair Chaudhry, Anthony Newton, and all the MSc GIS students (2007-2010) for the encouragement, motivation, and distractions over the course of this research.

Finally, I would like to thank family and friends for their continuing support through this PhD. Above all, thank you to Colin, you have been my rock throughout this process. You have been a consistent source of support, advice, sanity checks, happiness, and love. This could not have been achieved without you, and for that I will always be grateful. We can have fun now!

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Chapter 1

Introduction

Imagine that you have just arrived at the train station in a new and exciting city. You need to get to a nearby university for an important meeting. However, you have not visited the city before and you do not know the way, so you ask for directions from a passerby. What kind of information would you need to ensure that you got to your meeting both on time and without getting lost? What kind of features would you require in your directions? Landmarks? Streets? And how would you know that you are on the right track?

Finding the way to novel and unfamiliar destinations is a problem that affects pedestrians every day. Existing route description algorithms are limited in their richness and are primarily focused on car navigation. The majority of commercially available systems, for both pedestrian and car navigation, provide wayfinding descriptions based on street names and distance measures. For the pedestrian however, richer, more meaningful route descriptions are required, principally because the pedestrian is much less constrained in their choice of movement. It is widely recognised that landmark based navigation coupled with topological descriptions are an intuitive, amenable form of direction giving. The inclusion of landmark information within descriptions is therefore highly beneficial and provides a valuable extension to the more traditional street based route directions (May *et al.*, 2003).

Research into wayfinding, route descriptions, and use of landmarks has received a great deal of attention (e.g. Deakin, 1996; Denis, 1997; Sadeghian & Kantardzic, 2008). The inclusion of landmarks within route descriptions dramatically improves the chances of success in navigation, thus reducing the likelihood of getting lost. The selection and role of landmarks can be examined through virtual environments (Steck & Mallot, 1997) and real-world experiments. Such work can reveal when to include a landmark in directions, how efficient and reliable the inclusion of a landmark is, and hence can contribute both to the design of automated wayfinding technologies as well as validating the relative importance of landmarks identified from automatic landmark detection systems (Sadeghian & Kantardzic, 2008).

Currently available systems, such as Google Maps or Bing Maps, provide route directions for car navigation but are also developing methods to provide pedestrian focussed directions by including footpath information within their routing network. However, they fail to provide any additional landmark or feature of interest information within their descriptions, as their databases are not richly attributed enough. Google Streetview has, in part, been a reaction to this. This data, however, is too rich to be used in an automated manner and requires interpretation by the user.

In order to derive pedestrian focussed directions, which do not need the user to interpret all the data available, methods are required for the automated identification of landmarks that are key to the process of navigation. This thesis addresses this issue by investigating what constitutes a landmark, and its saliency, and discusses how this can be automatically extracted and modelled using spatial datasets that are currently available. The formation of route directions is also analysed. The result of this research is a pedestrian navigation system that automatically incorporates features of interest within the generated route descriptions to produce more natural and effective route descriptions. The pedestrian navigation system is a web-based system which provides both a map outlining the route as well as textual directions with references to features of interest. The recent developments of navigation technologies for smartphones would allow the ideas and techniques from this research to be adapted to these new mobile environments in the future.

1.1 Aim of Research

This thesis will assert that the derivation of useful and appropriately rich landmark based information for the inclusion in pedestrian route descriptions is possible in an entirely automated manner, using widely available pre-existing datasets.

The thesis will present methods to automatically describe routes in a more intuitive way for the pedestrian within an urban environment. Route descriptions should be meaningful, minimalist, and unambiguous to the navigator. The overall goal of the research is the creation of a pedestrian navigation system which automatically incorporates features of interest to present more natural route descriptions. The sub-aim supporting the development of the system is the automatic classification of features of interest to support the pedestrian navigation system.

1.2 Key Objectives

In order to meet the aim of this research, five key objectives were set out:

1. Investigate what makes a landmark salient
2. Determine the ways in which landmarks are used with route descriptions
3. Develop techniques for the automatic identification, extraction, and classification of landmarks in a urban area
4. Create a web based system that provides route descriptions which incorporate the automatically defined landmarks
5. Evaluate the automatically generated route descriptions

1.3 Structure of Thesis

This thesis is divided into nine chapters, following this introduction:

Chapter 2 introduces the relevant literature relating to cognitive maps, theories of navigation, models of landmark saliency, and automated landmark detection. This provides the background understanding required for development of an automated pedestrian navigation system.

Chapter 3 discusses the methodology to be used within the design, development, and evaluation stages of this research. This chapter also introduces the landmark experiments and the participants used within the three design experiments.

Chapters 4 and 5 analyse and describe the results of the three landmark experiments. These chapters reflect on how these results shape the modelling requirements for the pedestrian navigation system, both in terms of the saliency of features of interest and the textual information required in the route descriptions.

Chapter 6 outlines the technology used to build and develop the web-based pedestrian navigation system. The second half of this chapter outlines the various datasets used to identify the features of interest and create the corresponding variables measuring their saliency.

Chapter 7 builds on Chapter 4 by outlining the automated methods and techniques used for the creation of the variables to measure the saliency of a feature of interest.

Chapter 8 discusses the development of the pedestrian navigation system, including the creation of the saliency measure, the application of a visibility model within the system, and the generation of the route directions.

Chapter 9 presents an evaluation of the pedestrian navigation system through a final experiment, by comparing the system generated route directions with routes generated by currently available routing applications, and the type of natural directions given from person to person in the street.

Chapter 10 concludes the thesis by summarising the outcomes and major achievements of the thesis. The chapter also discusses possible areas for future research.

Throughout this research period, work from within this thesis was presented at the GIS Research UK (GISRUK) Conference in 2010, where it was awarded the prize for Best Paper by a Young Researcher. Additionally, a paper was accepted and published in GIS in Transactions in 2011. Copies of these papers are included as Appendix I and II.

Chapter 2

Literature Review

Wayfinding is a fundamental process of all large-scale environments (Golledge, 1999a). It is through the exploration of such environments that an individual builds a mental representation, or cognitive map, of an area. Individuals then use these representations to both plan and navigate their way through the environment. Wayfinding behaviour is, therefore, defined as "purposeful, directed, and motivated movement from an origin to a specific distant destination, which cannot be directly perceived by the traveller" (Allen, 1999; Tom & Denis, 2003). Based on this definition, Allen identified three categories of wayfinding tasks: travel with the goal of reaching a familiar destination, exploratory travel with the goal of returning to a familiar point of origin, and travel with the goal of reaching a novel destination. It is within this last category that individuals will often seek assistance with their navigation. This assistance can occur in a number of ways. First, they could be led to the location in question, second they could be provided with a pictorial or schematic representation of the route, or third they could be given a verbal response detailing the route (Denis *et al.*, 2001; Mendes, 2005). It is in these last two scenarios where the importance of route directions is most prominent. The basic function of a route description is to prescribe actions to the navigator that allows them to reach their destination with little or no difficulty. Recently, online navigation systems which provide street-based route directions (such as Google Maps, Yahoo Maps, and Bing Maps) have become a popular method of acquiring these directions. The production of route descriptions involves two major tasks, the determination of the route and the generation of the route's description.

Inherent to both wayfinding and route descriptions is the use of landmarks. Landmarks play an extremely important role when humans navigate through unfamiliar environments (Lynch, 1960). Previous studies have shown that individuals use landmarks during spatial reasoning and route communication. Landmarks are features of the environment that can act as a guide for individuals moving through an area. They are essentially used in directions as sub-goals along the route, thus linking different sections of the route together (Sorrows & Hirtle, 1999).

This thesis concerns itself with the automated generation of landmark based route descriptions. To fully understand how this can be accomplished, it is important to have an understanding of the key stages of wayfinding - to assess the veracity of route descriptions, and the role of landmarks.

This chapter discusses the foundation of this research by introducing literature relevant to the development of more natural route directions that include landmarks. The role of the cognitive maps within wayfinding is very significant as it determines the process of navigation, and helps to identify those features or landmarks that are most salient within the environment. It is the information stored within the cognitive map that the pedestrian navigation system is required to model, especially with relation to the process of identifying salient landmarks. The chapter also discusses the current models of landmark saliency and how these have been used to automatically detect landmarks to date.

2.1 The Cognitive Map and Wayfinding

The role of the cognitive map within wayfinding and the production of route descriptions is one of extreme importance and one that has been emphasised consistently within the literature. Lynch states that “within wayfinding the strategic link is the environmental image, the generalised mental picture of the exterior physical world, that the person holds” (1960, p. 4). Whilst Sigel and White state that "the primary function of the spatial representation is to facilitate location and movement within the larger physical environment and to prevent getting lost" (1975, p. 22). Finally Wunderlich and Reinelt describe the process that an individual goes through when asked for directions as

> "[they have] to activate a cognitive map of the relevant spatial areas, [they then] need to identify within this the location of the encounter (which will almost always be the starting point for the route described), [they] need to identify the location the 'questioner' is interested in (the end point of the route), and [they have] to select a suitable way of connecting these points or place" (1982, p. 183).

Cognitive mapping research has traditionally focussed on how humans navigate and acquire spatial information about the environment. This research shows that the majority of individuals use some kind of mental model of a region or city in order to generate and describe a route (Couclelis *et al.*, 1987; Garling & Golledge, 1993). More recently research has started to investigate how individuals mentally represent virtual environments and how to navigate through them (Albert *et al.*, 1999; Lazem & Sheta, 2005; Omer & Goldblatt, 2007; Steck & Mallot, 1997).

The development and application of cognitive maps is seen as an essential part of wayfinding (Darken & Peterson, 2002). It is often stated that the cognitive map is the first thing accessed when a person is presented with the requirement to construct a route in which to travel. The term 'cognitive map' was coined by Tolman in his seminal paper *Cognitive Maps in Rats and Men*. Tolman hypothesised that cognitive maps are representations formed within the mind by repeated experiences and that they are structured in the same way as traditional cartographic maps (Tolman, 1948). The term, however, was afforded little recognition until the 1970's when the cognitive map saw a marked increase in research amongst geographers and psychologists. This lead to the existence of a wide variety of definitions, primarily due to the multidisciplinary nature of the studies into the cognitive map (Kitchin, 1994). One of the most widely accepted and applied formal definition is offered by Downs and Stea who state that cognitive mapping

> "is a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment"
> (Downs & Stea, 1973, p. 9).

Whilst most researchers agree that, in general, the cognitive map is a mental representation of an external environment, the form that the cognitive map takes has seen much more debate (Tversky, 2000). Some researchers have argued that the cognitive map is purely the mental image of a paper map (eg. Gould & White, 1974; Kosslyn, 1980). Davis (1990), however, offers two mains differences between the cognitive map and the cartographic map. First the cognitive map may consist of different knowledge structures and second the cognitive map integrates incomplete, imprecise, and subjective knowledge. This is not the case for cartographic maps which are precise, complete, and only visually presented.

Other researchers have suggested that cognitive maps are actually mental models of the environment (eg. Johnson-Laird, 1983; Tversky, 1991). Mental models both capture and preserve the spatial relations among elements which allows for reorientation and perspective-taking to occur (Tversky, 1993). The idea of the *cognitive atlas* has been suggested by Kuipers (1982, 1983) and Hirtle (1998). The cognitive atlas refers to a collection of cognitive maps, existing at different scales. Finally Tversky (1993) introduces the idea of cognitive maps as *cognitive collages*. Cognitive collages are a combination of a variety of different sources of information about the environment that lack the coherence of a single map. The information is often taken from a variety of different viewpoints and unlike mental models they do not always logically preserve the spatial relations between elements of the map (Tversky, 1993).

In contrast to these differing ideas, Golledge (1999b) offers a simple definition of the cognitive map as an internal representation of the physical environment which denotes spatial knowledge of the environment, regardless of the form that the spatial knowledge takes. Finally, despite being referred to as spatial maps, Garling *et al.* (1984) states that is it important to note that the spatial knowledge contained within a cognitive map is often integrated with non-spatial information. Therefore, a broader definition of the cognitive map would be 'an internal representation of external physical environments which denotes both spatial and non-spatial knowledge of the environment, collected through experiences within the environment and often accessed when required to perform spatial tasks'.

The majority of research into cognitive maps and wayfinding has been focussed of trying to simulate the human behaviour in a computational model - for example TOUR (Kuipers, 1978), NAVIGATOR (Gopal *et al.*, 1989), and Ariadne (Epstein, 1997). These models include the simulation of the spatial cognitive process. Kuipers (1982) suggests that there is a strong link between cognitive processes and computation models based on the assumption that there is a strong similarity between them, in the sense that the manipulation of knowledge during learning and problem solving can be modelled by corresponding manipulations of data structured by computational procedures. There are a number of spatial questions that can be asked of a cognitive map including 'where is X?', 'how can I get to X?' and 'what is the shortest way to get to X' all of which can be answered by a computational navigation model.

One of the most recent computational models is Raubal's (2001) formal agent-based perceptual wayfinding model which focuses on peoples actual wayfinding needs (primarily in an unfamiliar environment) instead of focussing on learning a spatial environment. This is due to the fact that individuals attempting to navigate within unfamiliar environments do not have a mental representation of the area and therefore have different wayfinding requirements. Raubal implements a see-plan-action framework that allows for decisions to be made based upon the information presented within the environment to the navigator.

The focus of these models is on the creation and exploration of the cognitive map. However, they do not attempt to model the complete intricacies of how people really find their way. Gluck (1991) suggests that previous work has concentrated more on the description of the cognitive map whilst neglecting the affective and logistical concerns in most wayfinding situations. Golledge (1992) agrees with this, believing that computer models do not simulate the actual behaviour of wayfinders as they do not integrate asymmetric distances and directions. They also do not take into the account the personal preferences of the wayfinder, such as using areas they know well or areas they wish to avoid.

The cognitive map is an essential part of navigation and wayfinding. The basis of the cognitive map is to provide answers to spatial queries, with the research on internal spatial representations mainly focuses on how people use the cognitive map to aid navigation. This research history has led, in turn, to the development of a number of computational models that attempt to account for the cognitive processes that take place when performing wayfinding tasks.

The first computational model for the theory of wayfinding was TOUR which was developed by Kuipers (1978) and was based on the observations made by Lynch (1960). TOUR was a psychological model of human common-sense knowledge of large scale urban environments and it simulated the learning and problem solving behaviour of humans. It developed a cognitive map from simulated observations which was used to solve route finding problems. Other cognitive computer models have been developed to simulate the learning of spatial networks, for example TRAVELLER (Leiser & Zilbershatz, 1989), SPAM (McDermott & Davis, 1984), and ELMER (McCalla *et al.*, 1982).

The NAVIGATOR model integrates research from the fields of cognitive psychology and artificial intelligence to in order to represent the basic components of how humans process information. These processes include the filtering and selecting of important environment features and forgetting information. NAVIGATOR also addresses the four main aspects of spatial cognition including how the form of the mental representation, the way in which this representation is structured, the processes that the navigator may us in order to store and retrieve the information and the nature of spatial learning. (Gopal *et al.*, 1989). Ariadne is a computational program that allows for pragmatic navigation (Epstein, 1997). It learns about two types of features (facilitators and obstructers) to help describe a territory to aid two-dimensional navigation. Facilitators support efficient travel, whilst obstructers make travel more difficult and hence these form the model's cognitive map. More recent computational models are discussed within Section 2.6.

The cognitive map represents how individuals view the environment and stores information on what they perceive as being important features within that landscape. The primary function of the cognitive map is to help facilitate successful navigation through the space. This is applicable to this thesis as it is concerned with how individuals use their cognitive maps to create route descriptions and how they determine the most salient features within the environment. It is the ambition of this thesis to provide more natural route descriptions that reflect the type of information stored within the cognitive map. It is, therefore, necessary to discuss how this knowledge is collected, stored, and structured within the cognitive map.

2.2 Acquisition and Structure of the Cognitive Map

Cognitive maps are the basis for representing spatial knowledge (Moulin *et al.*, 1997). They are consistently developing throughout an individual's lifetime, based on their experiences (Klein, 1982). The cognitive map often contains different features that can be used to describe the environment and, in turn, routes through the environment. Lynch (1960) in his influential book, *The Image of the City,* offers a model of five elements that occur in the environmental images of an urban landscape: paths, edges, districts, nodes, and landmarks. *Paths* are channels along which the observer moves and *nodes* are located where these paths intersect to form junctions. Those linear elements that are not used or considered as paths by the observer are referred to as *edges*. *Districts* are medium to large sections of the city that have a common identifying character. Physical objects within these districts, such as buildings or monuments, which are identifiable from a distance are *landmarks*. These act as reference points within the city.

Two other models of the structure of spatial knowledge have been suggested: the Landmark Route Survey model and hierarchical models. The Landmark Route Survey model was initially suggested by Siegel and White (1975) and Thorndyke and Goldin (1983). The model accounts for both the elements included and the development process of the cognitive map. The Landmark Route Survey model takes the generally accepted view that landmarks and routes are the predominant elements of spatial representation. This has been extended by including configuration knowledge (more commonly referred to as survey knowledge) (Downs & Stea, 1973). The model states that, when developing a mental image of the area, the individual first extracts landmark information from the environment. These are considered to be strategic focus points which are disconnected from one another. Route knowledge then develops to connect the landmarks by paths. Finally, survey knowledge develops once there is complete integration between the landmarks and routes. This model fits directly with the elements of the cognitive map suggested by Lynch. Thorndyke and Hayes-Roth (1982) suggest that landmark route knowledge is the knowledge that individuals draw upon to move around an area whilst survey knowledge is the knowledge that allows the individual to understand the spatial relationships between places, regions, and landmarks. Survey knowledge, therefore, is the closest approximation to having a cartographic map in the mind. However, Montello (1998), argues against this step-wise approach to developing an environmental image and suggests that pure landmark and route knowledge do not exist. Rather Montello proposes that the development of spatial knowledge is a more continuous process which involves the simultaneous acquisition of landmark and survey knowledge.

Hierarchical modelling is an alternative to Landmark Route Survey models. Studies have suggested that spatial knowledge is more likely to be stored in a hierarchical model (e.g. Hirtle & Heidorn, 1993; Hirtle & Jonides, 1985; McNamara, 1986;

Stevens & Coupe, 1978). These hierarchical models are best summarised by the inclusion of distinct patterns of encoding at different spatial levels (Hirtle & Heidorn, 1993). Steven and Coupe (1978) provided the first empirical evidence that hierarchical spatial reasoning existed within the cognitive map. They found that hierarchies may arise due to the explicit structures applied to the environment, such as state or country boundaries. Hirtle and Jonides (1985) found that in addition to boundaries and natural phenomena, hierarchical organisations can also be based upon non spatial attributes such as the function of buildings (for example, commercial or educational) that an individual perceives within an area.

This hierarchical structure is also integrated within the *anchor-point hypothesis* of spatial cognition. The anchor-point theory states that there is a subset of anchors, called the primary nodes, which are the most salient and familiar landmarks in the space. It is these nodes that provide a "skeletal hierarchical structure for representing and organizing cognitive information about space" (Couclelis *et al.*, 1987, p. 99). This theory is, in turn, similar to Sadalla *et al.*'s (1980) idea of the degree of referentiality when describing reference points (landmarks) within the environment. These ideas of hierarchies have also been extended to suggest that they exist within the different elements of the cognitive map. For example researchers have looked at the hierarchies that exist between landmarks in the environment (Tsuchiya, 1988; Winter *et al.*, 2008) and also the hierarchies within street networks (Car & Frank, 1994; Tomko *et al.*, 2008).

2.3 Landmarks

Landmarks are often used in mental representations of space and the communication of directions. Various research has examined how landmark information is acquired and utilised when new environments are explored (Ishikawa & Montello, 2006; Siegel & White, 1975). Landmarks are defined as features of the environment that can act as signposts, at both the local and global level, to confirm progress, signal changes in directions, and link different sections of the route together (Sorrows &

Hirtle, 1999). They also enable individuals to encode the spatial relations between objects and paths enhancing the development of a cognitive map of the region (Heth *et al.*, 1997).

The term ‘landmark’ has been variously defined in the literature. Lynch (1960) views landmarks as points of reference which are external to the observer, and sees them as simple physical elements which may vary in scale. Lynch defines the key characteristic of a landmark as being its singularity, in other words some aspect of the landmark is unique or memorable. He notes that landmarks are more easily identifiable if they have a clear form, are in contrast to the background (are visually conspicuous), and have spatial prominence.

Some authors have defined landmarks in a very general sense with all points in the environment being landmarks (Siegel & White, 1975). Others, however, have argued that this is a minimal definition and give an alternative reading of landmarks as reference points which stand out from the background of the environment. The modelling of landmarks is critical to theories of spatial cognition (Presson & Montello, 1988). Raubal and Winter (2002) suggest that a landmark is an object or structure that marks a locality which is used as a point of reference. Their definition is based around the prominence or distinctiveness of a feature in a large-scale environment. There is a suggestion that the term landmark refers to a salient object in the environment that aids the user in navigating and understanding space (Sorrows & Hirtle, 1999). Sorrows and Hirtle (1999) also argue that the discrepancy in the definitions can be resolved by constructing a continuum of landmark values. They refer to Couclelis *et al.*’s (1987) anchor point theory which states that there is a subset of anchors which are the most salient and familiar landmarks in the space (Golledge, 1999a). In summary, landmarks are unique and salient objects that can play a critical role in helping individuals organize and navigate large-scale environments.

2.4 Landmark Saliency

The concept of saliency, in this thesis, refers to the landmark as possessing qualities that attract attention to it. These qualities make the landmark prominent, striking, remarkable, and noticeable. This makes it unique amongst the surrounding area. Modelling saliency is important because it allows such landmarks to be identified within the urban landscape and, in turn, aids the development of systems that can automatically identify the most appropriate features to include within directions.

There have been several attempts to formally characterise the salient qualities of landmarks. Sorrows and Hirtle (1999) developed a typology of landmarks. They proposed that landmarks could be characterised in terms of four factors: singularity, prominence, meaning, and prototypicality. *Singularity* (as defined by Lynch (1960)) applies to features that are in sharp contrast to the surrounding environment, whilst *prominence* relates to the spatial location of the object. Some landmarks are used because they have certain *meaning* associated with them, such as historical or cultural importance. *Prototypicality* is where individuals refer to the object because they are typically representative of a specific category of landmark. Based on this characterisation, Sorrows and Hirtle identified three categories of landmarks: visual landmarks (those with a visual contrast), structural landmarks (those with a prominent location), and cognitive landmarks (those defined by their use and meaning). This typology was developed for use in both the physical environment and electronic space. Despite this, few attempts have been made to formally characterise the qualities of landmarks.

The description of landmarks by Sorrows and Hirtle is one of the most influential characterisations in the literature. The typology put forward was extended by Raubal and Winter (2002) into a formal model of landmark saliency to determine the strength of a landmark. This was based on the belief that a landmark is stronger the more positive qualities it possesses. Raubal and Winter adopted the three categories of landmarks suggested by Sorrows and Hirtle and assumed that the visual, semantic, and structural attraction of features within the physical environment determined their use as a landmark. A landmark is visually attractive if it has certain visual characteristics (for example if it sits in contrast to the surrounding area). Four measures of visual attraction were used within the model: façade area (size of the frontage of the building), shape, colour, and visibility. Visibility is measured as the area of space visible from the front of a building. Semantic attraction focuses on the meaning of a feature and was included in the model using measures of cultural and historical importance and explicit marks. Explicit marks refer to the signage located on a building. Finally, a landmark is structurally attractive if it has a prominent location in the structure of the spatial environment. This was included in the model as measures of nodes and boundaries. These measures were then used to calculate a numerical estimation of the landmark's saliency. The landmark with the highest value was determined to be the most salient feature and thus be the most appropriate landmark to use at that decision point.

Raubal and Winter's formal model has been tested and modified several times since being first proposed. Nothegger *et al.* (2004) tested the initial model and found that, in general, the results reflected the ability of the model to compute the most salient building around a decision point. Winter (2003) then extended the model to include the idea of *advance visibility* as it is more practical to select a building that is relatively salient and visible early to an individual traversing a route. Advance visibility is defined as a combination of how much of the route is covered by the area visible from the features façade and the orientation of the feature to the route's heading. The model was extended for a second time by Winter *et al.* (2004) when they introduced the concept that the saliency of a building is dependent on the wayfinding situation, such as the mode of transport of the individual, the role of the individual, or the time of the day. Finally, Klippel and Winter (2005) followed on from this work by developing taxonomies for the structural attraction of a landmark where a building is considered structurally salient if its location is cognitively and linguistically easy to understand in a set of route directions.

Whilst Sorrows and Hirtle's (1999) typology is the most referred to in the literature, there have been several other attempts to classify the saliency of landmarks. Caduff and Timpf (2008) argue that salience of a landmark is not an inherent property of the feature - rather it is a combination of the feature, the surrounding environment, and the observer's point of view. This differs from the traditional view of a landmark being a distant object (for example an outstanding building) within the environment. Based on this idea of salience they developed the *Saliency Vector* which accounts for the relationships between the observer, the observed object, and the environment in terms of perceptual, cognitive, and contextual salience. The saliency vector expresses the overall potential of the landmark in attracting the navigator's attention.

Burnett (2000) and Burnett *et al.* (2001) offer a different characterisation of landmarks (albeit for car navigation). They suggest permanence, visibility, usefulness of location, uniqueness, and brevity as the main aspects of landmarks. The characteristic of permanence relates to the likelihood of the landmark being present in the environment, while visibility refers to whether the landmark can be clearly seen in all conditions. Usefulness of location relates to whether the landmark is located close to navigational decision points. Finally, uniqueness looks at the likelihood of the landmark not being mistaken for other objects and brevity refers to the conciseness of the description associated with the landmark.

More recently, Sadeghian and Kantardzic (2008) have argued that dynamic variables (such as visitor numbers) must also be included in the measure of saliency, since this will influence knowledge of landmarks, even when they are not physically distinct. To some degree such dynamic variables can be accounted for by the building's function (a public library, or small pub can have high landmark saliency, for example, without knowing visitor numbers).

There are a variety of different characterisations of landmarks in the literature, however, it is clear that for a landmark to be salient, it must be sufficiently unique, clearly visible, stand out from its surrounding environment, and be located close to a navigational decision point.

2.5 Landmarks in Route Descriptions

It has often been found that routes enriched with landmarks lead to better guidance, quicker assimilation, greater confidence, and fewer wayfinding errors than routes primarily based on street names. There is a substantial body of literature documenting the numerous experiments that researchers have undertaken to test the differences between the use of landmarks and street name (for example Allen, 2000; Deakin, 1996; Denis, 1997; Michon & Denis, 2001; Tom & Denis, 2003). Recent research has investigated the role of landmarks within route directions (Fontaine & Denis, 1999; Lovelace *et al.*, 1999; Werner *et al.*, 1997) and affirmed the importance of landmarks as an essential part of route descriptions (Daniel & Denis, 1998, 2004; Denis *et al.*, 1999; Tom & Denis, 2004; Weissensteiner & Winter, 2004). Research into landmarks and route descriptions has primarily taken two separate directions. Firstly, researchers have investigated which landmarks are most appropriate to be included in route directions (Allen, 2000; Deakin, 1996; Denis, 1997; Tom & Denis, 2003, 2004). Secondly, researchers have investigated the success of using pre-selected landmarks in route directions (Denis *et al.*, 1999; May *et al.*, 2003; Sefelin *et al.*, 2005)

The use of street names in route descriptions can lead to a variety of problems as they may not be visible, the names are often arbitrary, and they generally contain no spatial or descriptive information about the surrounding environment. On the other hand, it is noted that street names are concise and generally only occur once in the local area, thus providing an easy way to construct route directions (Tom & Denis, 2003). When studying the differences between the use of landmarks and streets names as components of route directions, Tom and Denis (2003) found that *checkings* (an expressed intention to check some features or a piece of information such as a street name) and stops were significantly less frequent and significantly shorter for those participants who used landmark descriptions as opposed to those using street based directions. Participants were also asked to draw a map of the route for which they had just traversed. These revealed that those participants directed through the environment solely by landmarks, only incorporated landmarks on their maps of the area. However, those participants directed through the environment only by streets, incorporated more landmarks than street names on their maps. In a separate study, Tom and Denis (2003) observed that the when a person is traversing a route they included streets less often than landmarks, with the directions containing twice as many references to landmarks than to streets. Michon and Denis (2001) also observed that participants had trouble following skeletal street-based instructions and often mentioned the need for landmarks to be included in the instructions. In a subsequent study, Tom and Denis (2004) investigated the effectiveness of route descriptions that were either landmark or street based and found that those directions with landmarks took less time to process than street names and that participants could, in general, recall more landmarks than streets. These studies show the importance of landmarks within an individual's cognitive map, and illustrate the critical role landmarks play in the processing of route directions.

Supporting the finding of Tom and Denis, Ross *et al*. (2004) conducted experiments in which participants were walked through an unfamiliar route using text based navigation instructions that were either enhanced with the use of landmarks or not. These experiments showed that the addition of landmarks to pedestrian route directions improved navigation performance and increased user confidence. The inclusion of landmarks at decisions points have also been shown to improve the effectiveness of pedestrian navigation using memorised route directions (Allen, 2000) leading May *et al.* (2003) to argue that landmarks should be used as the primary means of providing directions.

Whilst landmarks are of major importance for guiding people, the frequency with which they are utilised in route descriptions is subject to individual (and often gender-based) preferences. Several researchers have found that females refer to visual landmarks more frequently than males (Denis, 1997; Galea & Kimura, 1993; Ward *et al.*, 1986). Ward *et al*. (1986) found females more likely to refer to environmental features when giving route directions whereas males included more references to metric distance and cardinal directions in their descriptions. The findings of Ward *et al*. were supported by Allen (2000) who found that females were more successful at wayfinding when environmental object descriptions were included in their directions. However, Allen also noted that males did not necessarily perform more accurately with instructions that emphasised distances or directions.

As well as looking at individual preferences in the use of landmarks, research has also been conducted examining the use of landmarks within route directions in different types of spaces. Studies have considered areas such as cities (Denis *et al.*, 1999), university campuses (Goodman *et al.*, 2004), indoor environments (Fontaine & Denis, 1999; Sefelin *et al.*, 2005), electronic space (Sorrows & Hirtle, 1999), and virtual environments (Lazem & Sheta, 2005; Omer & Goldblatt, 2007; Steck & Mallot, 1997). Additionally, work has been done on the use of landmarks by children (Cornell *et al.*, 1989; Cousins *et al.*, 1983; Heth *et al.*, 1997) and older people (Goodman *et al.*, 2004).

The location of landmarks as navigational aids has been amply documented. Lovelace *et al.* (1999) distinguishes between landmarks at decision points, potential decision points, route marks, and distant landmarks. They found that decision points and route marks are the most commonly used when navigating through unfamiliar environments. Similarly, Michon and Denis (2001) suggested that the three most important reasons landmarks are required are; to signal where an action should be executed, to create the link to the next section of the route, and to reassure navigators that they are still on track.

It has been observed that, within an urban environment, the use of landmarks is not evenly distributed along the route described. Instead they tend to be at locations where reorientation decisions are required. (Denis *et al.*, 1999; May *et al.*, 2003; Michon & Denis, 2001). Landmarks tend to also be located at locations where reorientation could occur, such as in places where several possible directions could be followed (Michon & Denis, 2001). In addition, May *et al.* (2003) found that information is also required between key decision points to promote user orientation and trust.

Additionally, Lynch (1960) distinguished between distant and local landmarks. Distant landmarks are prominent objects that are visible from many locations, however, they are rarely used in navigation except for directional orientation. In contrast, local landmarks are only visible in restricted localities and are much more often employed for navigation purposes.

Employing Lynch’s idea of distant and local landmarks, Golledge (1999a) argued that landmarks can serve two purposes, they can either be an organising concept for space (distant landmarks) or a navigational aid (local landmarks). When organising space, landmarks can represent a cluster of objects at a higher level of abstraction or scale whilst also presenting an anchor for understanding local spatial relations. Examples of such landmarks are the Eiffel Tower in Paris and Edinburgh Castle in Edinburgh. These landmarks can help to represent individuals understanding of an entire city. On the other hand, landmarks in navigation serve an entirely different purpose. They identify choice points where navigational decisions are made. They may also identify the start and end points of a route and provide verification of the route to the individual. Therefore, whilst local landmarks are primarily used for navigation tasks, global landmarks can be used to confirm that the navigator is facing the right direction in the beginning and confirms that they are on the right track as they progress through the route.

Finally, when using landmarks within route directions Sefelin *et al*. (2005) states that landmarks should fulfil two main criteria. First, they should be a distinctive feature (easily detectable within the area) and second that the feature should be unambiguous in its naming. In terms of unambiguous naming, May *et al*. (2003), found that wherever possible the name of landmarks should be referred to rather than a general description. Denis *et al*.(1999) collected descriptions of three different routes in Venice and found that even though a large variety of landmarks were mentioned they could be divided into two categories: two dimensional horizontally extended entities (such as streets, bridges, and squares) and physical 3D objects (such as buildings). The most frequently mentioned landmarks were ground-based entities (such as streets and bridges) which supported navigation and were often included as features to follow.

This thesis concerns itself with the use of landmarks within route descriptions; which landmarks are used, why are they used, and how are they included. The thesis also, however, seeks to expand upon the research discussed above, with the specific aim of developing an automated system that selects and incorporates appropriate landmarks within pedestrian route directions.

2.6 Automatic Detection and Classification of Landmarks

Recently research has moved from being concerned with finding the most appropriate landmarks and seeing how successful they are in navigation experiments to looking for ways to detect landmarks automatically from available datasets and how these landmarks could be best integrated into current wayfinding descriptions (Caduff & Timpf, 2005; Nothegger *et al.*, 2004; Richter, 2007; Sadeghian & Kantardzic, 2008).

The main challenges when examining the use of landmarks within route descriptions are the automatic definition and extraction of appropriate landmarks from existing datasets (Raubal & Winter, 2002). Based on the formal model of landmark saliency proposed by Raubal and Winter (2002), Nothegger *et al.* (2004) tested and refined this model of landmark salience using measures related to building façades. They found that the model was a viable assessment of the saliency of landmarks. This attempt was not fully automated; the outline of the façade for each building had to be manually determined in order for the related measures to be computed.

Taking a different approach, Elias (2003a, 2003b) investigated whether it is possible to extract salient objects from spatial databases using methods of spatial data mining. Elias's research focuses on an approach to automatically select landmarks from a building database. A number of geometric and topology attributes are identified, including size, use, height, distance to the road, orientation to the road, and number of neighbouring buildings. A hierarchical clustering approach is then applied to determine which buildings are potential landmarks. Clustering results in objects that are similar being grouped together whilst unique salient objects stand out, therefore becoming potential landmarks. This work shows some promise in being able to data mine for building based landmarks. Elias used the definition of Sorrows and Hirtle (1999) and used Raubal and Winter's (2002) model of landmark saliency. This work discussed the possible use of linear landmarks such as rivers.

Elias' work (2003a, 2003b) has been extended by Elias and Sester (2006) who developed an approach to provide landmark based descriptions using a shortest path algorithm. This approach included a method of selecting the optimal landmarks from a set of potential landmarks using quality measures (Elias & Sester, 2006). These quality measures were based on those developed by Burnett *et al*. (2000).

Lazem and Sheta (2005) also used spatial data mining methods to extract five measures of a building's properties (height, colour, importance/activity, width, and location in street in relation to the other buildings) for three virtual city environments. They developed a spatial outlier detection algorithm which identified the most salient buildings by analysing the five variables and finding the buildings whose values were significantly different from its spatial neighbours. Lazem and Sheta evaluated the significance of the algorithm and found that the results proved that the algorithm can successfully identify landmarks.

Another author who has included landmarks within route directions is Richter (2007) who developed GUARD (Generation of Unambiguous, Adapted Route Directions), a computational process that generates route directions which take into account a variety of different types of landmarks, such as point-based landmarks, linear landmarks (such as rivers), and distant landmarks. Within GUARD the route is represented as a directed graph with the decisions points being any node that has a degree of three or higher. The process then generates a set of text-based directions for the route; however, the landmarks are not generated automatically as they are pre-determined and are assigned to a particular decision points.

Caduff and Timpf (2005) believe that the question as to which route offers the clearest cues and how to integrate these into route instructions is poorly understood. They developed a cognitive model (the Landmark Spider) that takes the saliency of the object into account from a traveller's perspective (i.e. heading and distance). The model assesses the relevance of the landmark from the perspective of a person travelling the route and includes the selected landmarks in the route's description. Caduff and Timpf suggest that the typical way of incorporating landmarks is to enrich the street descriptions of the route with landmark information. Their approach is different in that it uses a subset of all available landmarks to determine the clearest route, thus avoiding areas of low landmark density. They made the assumption that landmark information was only to be given at the nodes of the route; therefore no confirmatory landmarks are given to the user along the edges of the route. This work is focused more on the generation of landmarks within route descriptions than the automatic generation of landmarks themselves, thus the landmarks and their saliencies are pre-coded into the system. The output of the model is a diagrammatic representation of the route. The landmarks included on this map are selected on the basis of the saliency of the object, and the distance and orientation from the user.

Another approach taken by several authors has been to investigate the ways in which the Internet could be used as a means of identifying potential landmarks. Tezuka and Tanaka (2005) suggested web data mining as a possible method of acquiring knowledge about landmarks, with the initial results from this method being highly correlated with human judgement of what defines a landmark. Tezuka and Tanaka suggest that the most appropriate landmarks maynot be only those which are visually significant but also are those that are frequently used by individuals. They modified existing textual mining methods to include a spatial context and used these improved methods to mine the internet, via search engines to successfully determine landmarks within Kyoto. Similarly, Furlan et al. (2007) used web mining to develop a method for the classification of landmarks as either point-like, line-like, or area-like objects for use within route descriptions. The methods they developed relied on the verbs and prepositions that occurred alongside the landmark in the online descriptions. However, they were able to achieve high levels of agreement between the results of the data mining methods and a set of manually classified landmarks. More recently, Popescu et al. (2009) developed data mining methods to automatically construct geographic gazetteers. Using websites including Wikipedia and Flickr they demonstrated how a gazetteer of geographic objects could be constructed which included the object's name, GPS coordinates, region, type of object. They also explored how the popularity of an object could be estimated by using a data mining method that repeatedly filtered information found in the web pages and cross-checked the information with that found from additional sites.

These recent developments in the use of data mining techniques show that it is becoming increasingly possible to mine the internet to gather much of the information required as input to an automated pedestrian navigation system. This is not just limited to the identification of landmarks, but also includes extracting information relating to specific features. Such additional information could, for example, include vernacular names for the features. In summary, data mining methods are now advanced to the stage that they can assist (but not yet completely replace) the task of constructing landmark datasets. Their potential to provide information about landmarks will increase as the richness of online content improves. Data mining methods area currently able to provide navigation systems with supplementary information about landmarks within the environment, however, this will not replace human searching and data structuring in the near future.

Finally, several authors have created navigation systems that have been developed with the support of handheld computers using photographs of landmarks as aids to route directions (Beeharee & Steed, 2006; Goodman *et al.*, 2004; Kray *et al.*, 2003). Millonig and Schechtner (2005) discuss the possible development of a navigation system for pedestrians using mobile phones as a navigational aid.

2.7 Summary

Current pedestrian navigation systems primarily use maps combined with positioning and network routing information. None of the commercially-available systems include landmark information. The research has, however, shown that the inclusion of landmarks within route descriptions not only improves an individual's confidence in their navigation but also removes the majority of wayfinding errors, compared to using street-based route directions. In terms of deciding which landmarks to use, it has been noted by numerous researchers that the landmark needs to be unique, memorable, and that it should stand out from the surrounding area. Current trends in the research are to look for ways in which potential landmarks can be both automatically detected from available datasets and how they can best be integrated into current wayfinding descriptions. To date, however, no single solution has been developed to automate both of these tasks.

Whilst many systems exist that deliver wayfinding instructions for car navigation, few commercial systems exist for pedestrians. A number of research projects have, however, investigated the development of a system to provide pedestrian route descriptions enriched with landmarks (May *et al.*, 2003; Millonig & Schechtner, 2005; Richter, 2007). There is, therefore, a need to develop a system entirely for pedestrians, which utilises landmarks and that can be made available for individuals to use on a daily basis.

Research has shown that including landmarks within route descriptions is highly beneficial, dramatically improving the chances of success and reducing the likelihood of getting lost. The investigation into the role of landmarks within route directions in the literature, however, has been primarily conducted in two ways; analysing which landmarks are most appropriate to use and testing the success of the inclusion of landmarks. The investigation into how to automatically define landmarks has only begun in the last few years. Within the majority of this research, the landmarks are often pre-selected by the researchers and are included by hand in the route directions or are hard-coded into the wayfinding device developed.

Problems, therefore, exist in these solutions. Selecting and including landmarks by hand can become considerably time consuming and expensive when extending the project outside a sample area (to a different location or scaling up to a city level) or when wishing to replicate the solutions within a different city. Additionally, the person defining the landmarks may also introduce bias and error into the system, as individuals often have different viewpoints and preferences as to what makes the 'best' or most salient landmark in the area.

Finally, it is crucial that the most salient object is one that stands in contrast to its background, however, only a handful of researchers have attempted to model this within their work. Whilst research into the use of landmarks within route descriptions is well advanced, research into the automatic detection of landmarks, and the automatic inclusion of these landmarks within route directions has only begun to gain momentum. This thesis can therefore build upon the ideas already in the literature to develop a system that is fully automated, from identifying all the potential landmarks in a city to including references to these landmarks in automatically generated written route descriptions.

This chapter has argued that the understanding of how pedestrians think and perceive the environment as they navigate is critical to the development of an automated system that generates route following instructions. The understanding and provision of landmarks that are salient and meaningful is essential to the creation of easy, unambiguous route directions. Hence, this needs to be modelled within any system that is developed. Finally, for such navigation systems to be scalable, a level of automation must be achieved to allow the population of the system with a complete set of landmarks and their associated saliency measures. The next chapter builds on the ideas gathered from this literature review to outline the methodology used to investigate the saliency of landmarks within the City of Edinburgh and the development of an automated pedestrian navigation system.

Chapter 3

Methodology and Experiment Overview

Chapter 2 outlined the current body of literature, evidencing the utility of landmark information within route descriptions. The inclusion of such features not only aids confident navigation by the user, but also reduces wayfinding errors. Despite this however, real-world applications designed to provide automated routing information do not at present include such information.

The ambition of this research was to develop a fully automated pedestrian navigation system with feature-rich route descriptions. In order to inform the way in which feature information should be implemented in an automated system however, further empirical evidence was required on the way in which individuals perceive the urban landscape when traversing a route. Such evidence could then be used to inform the implementation of feature information in an automated system, thus enabling the system to identify the routes and specific features that would be of most use to an individual.

The research is intended to be applicable to any urban area, however, was limited to the city of Edinburgh for the initial analysis. The focus of this research is limited to urban areas due to the differences that exist between landmarks within rural and urban areas. Navigation within rural areas requires a different set of landmarks, for example a multi storey building may not be salient in a city, however can become very salient within an rural area. Additionally, different types of landmarks can become important within rural areas. For example natural features have a much larger role to play in navigation in a rural setting than in a city. Navigation in rural areas also requires earlier visibility of upcoming features of interest due to wider vistas and lower density of features. The methodology for creation of a pedestrian navigation system was split into three sections; the design stage, the development stage, and the evaluation stage (Figure 3.1). The design stage incorporated three field-based experiments aimed at investigating the variety of landmarks that are typically used within verbal route descriptions. The results of these experiments determined the overall modelling requirements for the system. The development stage included the creation of a *features of interest* database and the algorithms required to generate their associated variables of saliency, the feature-rich route, and the textual descriptions. The final stage evaluated how efficiently the directions generated by the pedestrian navigation system reflect the more natural route descriptions that people generally create based on a cognitive map. The evaluation was carried out through a final field experiment which collected a set of directions from a sample of individuals with knowledge of the study area. This chapter covers an overview of the methodology for the three stages of the research along with a more detailed look at the methodology for the three design stage experiments. The detailed methodology outlining the build stage is discussed in Chapters 7 and 8, whilst the evaluation experiment's methodology is detailed in Chapter 9.

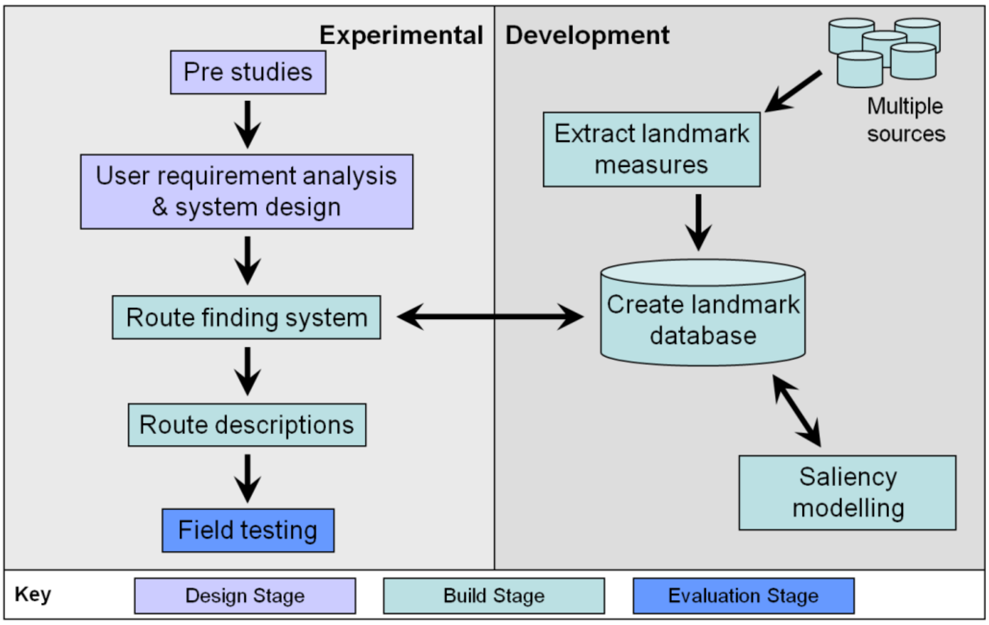


Figure 3.1: Overview of the research methodology

3.1 Study Area

The City of Edinburgh was the focus of this research and the area outlined in Figure 3.2 is the study area that was used. This area covered the majority of Edinburgh including the Old Town, New Town, Leith, and Liberton sections of the city. The study area was chosen because it included varied relief and a mixture of features of interest; large versus small, old versus new, natural versus cultural. Edinburgh also presents its own challenges in that it is a multi-level city where routes and features can pass over or under one another.

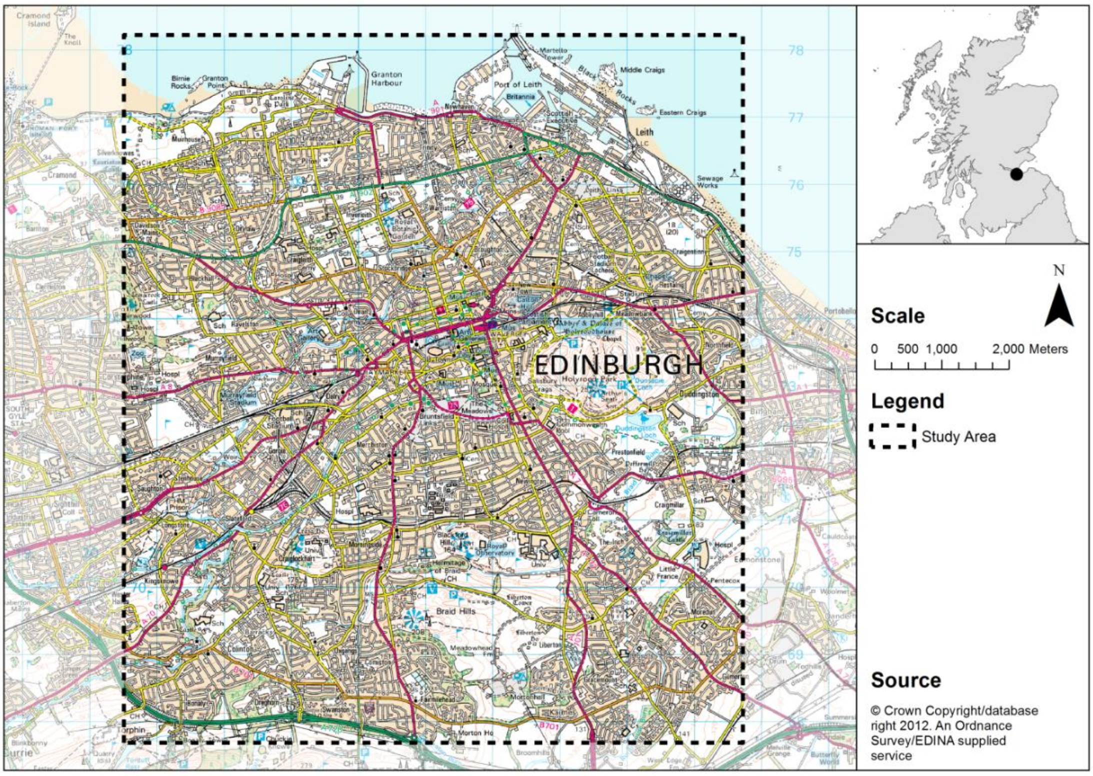


Figure 3.2: Area of Edinburgh that was used as the study area

3.2 Method

The three stages of the research methodology are described below.

3.2.1 The Design Stage

This stage was interested in investigating the role that landmarks play within route directions. More specifically, how do these features of interest stand out from the environment, what makes them salient, how are they referred to within direction giving, and where are the features located in relation to the route? Three experiments were created to investigate and gather empirical evidence to answer these questions. The first experiment sought to identify those features in the environment that were salient to the participants and identify the reasons as to why. The second experiment explored the way in which route descriptions are formed when traversing a route. This experiment examined how the features were included in the descriptions (primary direction cues, confirmatory cues, or 'you have gone too far' cues). The third experiment investigated a participant's recollection of the route that they had just traversed, providing an insight into which features of interest an individual would choose if required to give a set of directions to a friend. The design of these three experiments was inspired by the work of Michon and Denis (2001), Tom and Denis (2003, 2004) and May *et al.* (2003).

The analysis of the three experiments formed the basis of the design specifications for a fully automated pedestrian navigation system that takes into account features of the environment and their associated saliency. These design specifications established what features of interest needed to be taken into account when developing landmark-based route descriptions and determined their associated measures of saliency.

An overview of the experiments, including the participants, routes used, and the methodology are outlined in Section 3.3 of this chapter whilst the results and their implications for the creation of the automated pedestrian navigation system are discussed in Chapter 4 and 5.

3.2.2 The Development Stage

The development stage was comprised of four separate tasks; the creation and population of the features of interest database, the development of the saliency model, the programming of the route generation algorithm, and the conversion of the route into written route descriptions.

The creation of the features of interest database included the development of the attributes relating to the measures of a feature's saliency (for example height, footprint area, use, cultural significance) which were extracted from a variety of different datasets, gathered together from numerous sources. This database is accessed by both the saliency model and the route generation algorithm to determine which landmarks are the most appropriate to use within the route descriptions.

Using the findings from the three experiments, a saliency model was developed to allow for the comparison between the different features of interest, thus identifying the *most* salient features to use within the route directions. Selecting the most salient feature required the development of a visibility model which defined the features in the surrounding environment that needed to be taken into account when determining the overall saliency of an individual feature. It is often stated in the literature that the landmarks that are more often referred to are those that are in contrast to the background, therefore, this needed to be reflected in the system (Lynch, 1960; Sorrows & Hirtle, 1999).

The route generation algorithm was developed based on Dijkstra shortest path algorithm (Dijkstra, 1959). The routing algorithm was extended to ensure that the route takes the navigator through landmark rich area as opposed to areas devoid of landmarks ('landmark deserts'). The final part of the build stage was the conversion of the route generated into a set of textual instructions, incorporating references to the most salient features at each reorientation point. Additionally, the textual descriptions included confirmatory 'you're on the right track' cues along the route.

The development stage is discussed in detail in Chapters 7 and 8 whilst the datasets and technology used is outlined in Chapter 6.

3.2.3 The Evaluation Stage

The final stage in the research was evaluation of the route description generated by the pedestrian navigation system. The aim of testing the route descriptions was to see how efficiently the pedestrian navigation system reflected the more natural and richer route descriptions that people typically generate from their cognitive map. This included assessing whether the directions generated by the pedestrian navigation system were reflective of those that are used in the real world, and whether the system had identified the most salient features of interest in relation to how different individuals perceive the environment.

Two locations were selected as the start and end point for the route to be described. For each of the locations, twenty people were asked to provide a set of directions which would allow someone unfamiliar with the city to navigate to the other location. There was no set route that the participants needed to follow, they were, in theory, able to pick the route which was easiest for them to describe. The start and end points were selected as they provided the opportunity for a variety of potential routes between them to be identified and used. Collecting directions from both locations allowed for the system generated descriptions to be tested to observe whether or not the system accurately accounted for visibility. Additionally, directions gathered from the participants were compared and contrasted to the system generated route descriptions by investigating how well the features of interest chosen by the participants were reflected in the automatically generated descriptions and by looking at the way the descriptions were composed. The results for this experiment are discussed in full in Chapter 9.

3.3 The Landmark Experiments

Despite the substantial body of literature, there have only been a handful of attempts to specifically define how to measure a landmark's saliency within a given environment. Questions remain as to how to identify and automatically extract these features of interest from the environment, and how to classify and prioritise their use in formulating route descriptions. The following three experiments were developed to provide answers to these questions. The experiments looked at the requirements for automating the inclusion of feature of interest information within route directions, from deciding the variables of saliency, the variety of features (for example buildings, monuments, streets) that need to be considered, and the location of where the references to these features should take place within the direction giving process.

The first experiment set out to identify the vocabulary used to describe features of interest in the environment. This sought to identify those features that stood out to the participant and to investigate the reasons as to why they stood out. The participants walked along the route, guided by the author of the thesis, without knowledge of the destination and were only directed once they arrived at corners (for example 'we will turn left here'). They were asked to identify and discuss any unusual, distinct, striking, or interesting features that stood out to them as they walked along the route.

The second experiment explored the way in which route descriptions are formed when traversing a route. The results of this experiment provided a very detailed set of descriptions, which reduced down the large number of features that were identified in *Experiment One*. The features were examined to identify the reasons why certain features were selected more often than others and how they were included in the descriptions (primary direction cues, confirmatory cues, or 'you have gone too far' cues). The participants were led along another route, different to that used in the first experiment, and again did not know the destination. They were asked to develop a set of route directions for a friend to follow as they walked along the route and were encouraged to discuss the reasons behind their selection of each directional cue.

Finally, the third experiment looked at the recollection of the routes that were walked during experiments one and two. The participants were asked at the end of each experiment to provide a set of directions for the route that they had just walked from memory. This provided an insight into which features of interest the participant would choose if required to give a set of directions to someone, whilst also identifying those features that were most memorable.

The aim of the three experiments was to investigate how features of interest are used within verbal route descriptions. Within this in mind, the five specific objectives of the experiments were:

1. Identify the features that are deemed to be salient in the urban landscape and the reasons why
2. Include reverse directions to see if different features are more noticeable
3. Investigate if familiarity with the area affects the features being recollected
4. Determine whether simpler routes draw fewer features
5. Measure the difference in male and females

The results of the three experiments were used to form responses to these five key questions. In turn, these responses formed the basis of the design specifications for the pedestrian navigation system. These design specifications stated what features of interest (for example buildings, monuments, statues) needed to be taken into account when developing route descriptions and determined what measures of saliency (such as height, area, colour, function) were required to be extracted and stored as variables in the features of interest database. Additionally, the analysis determined how the variables should be used to develop the mathematical model of landmark saliency.

Pairs were used as it was found via testing of the experimental methodology that when one participant undertook the experiments the conversation was limited and often they would try and engage the person leading the experiment in the discussion. This resulted in the lack of information required for the successful outcome of the studies. It was therefore concluded that using pairs provided the level of detail and discussion required for the experiments. Interestingly, anticipated problems, such as one participant dominating the discussion or the pairs not interacting well with one another were not experienced. This is believed to be due to the nature of getting the pairs to volunteer together rather than the experiment leader devising the pairs.

3.3.1 Experiment Methodology

Forty participants were gathered through an email which was sent to all students (undergraduates and postgraduates) within the School of GeoSciences at the University of Edinburgh advertising a request for volunteers to take part in the experiments and stating those selected would be paid. The students who were interested replied using an online form that identified those who wished to take part and the day and times they were available. Participants were selected on a first come basis and were assigned a day, time, and randomly allocated a starting point which determined the order and directions of the routes. Participants were asked to volunteer in pairs as it was felt that due to the discussion nature of the two tasks it would be easier for the participants to discuss, agree, and disagree with one another if they knew them before-hand.

The selected participants were provided with an information sheet and asked to complete a consent form required for ethics, a questionnaire, and a familiarity map that were to be completed prior to the experiments. These forms and questionnaire are included in Appendix III. It was important to record their familiarity with the study area as it enabled analysis of the effect that previous knowledge has on the participant's recall of the route and features in the environment in *Experiment Three*.

They were then given the following instructions for *Experiment One*:

> *The aim of this task is to identify and discuss any unusual, distinct, striking, or interesting features that stand out as you traverse the assigned route. It is important that you not only identify the feature but also discuss why you find it significant.*

Directly upon the completion of *Experiment One*, each participant was asked, individually, to give a short set of directions of the route that they had just traversed (this was recorded for *Experiment Three*). Once both participants had done this they were led to the starting point for the second route and given the following instructions for *Experiment Two*:

> *The aim of this task is to identify the landmarks that you would use when giving a description of the route for a friend to follow. You are encouraged to discuss reasons for including each of the landmarks. You can disagree with each other and suggest alternative landmarks that you believe would be more appropriate.*

As at the end of *Experiment One*, the participants were asked to recall the route. As *Experiment Three* was conducted on both routes for all participants and was relying on their memory of the route it was completed at the end of Experiments 1 and 2. Each task was not explained to the participants until they were about to start. Upon completion of all three experiments the participants were paid and asked to sign a payment receipt form. Both individuals in the pair were voice recorded and the traversing of the route was videoed. Videoing the experiments enabled the author to have a visual reference of the route at the time of the experiment and allowed for the clarification as to which features of interest were being discussed. These were then transcribed and analysed by the author of this thesis. Each statement in the transcriptions was attributed to the participants who said it. However, in general, the analysis for experiments one and two were more focussed on the joint discussion and all the features identified within the transcriptions, rather than analysing it by each participant. *Experiment Three*, however, took the information about the participants into account during the analysis. The results of the analysis of the transcriptions are discussed in Chapters 4 and 5. Example transcripts for the three experiments are included as Appendix IV.

3.3.2 Routes

Two routes were developed within the study area that were approximately the same length, a mile long and taking 20 minutes to traverse walking (Figure 3.3). Two routes were used in order to allow for analyses of how the complexity of the route changed the information that was provided by the participants. The complexity of the routes was based upon the number of reorientation points and possible re-orientation points along the route. The same routes were used for the three experiments enabling comparisons to be made between the results of the experiments. Combining the findings from each experiment ensured that a more detail picture was obtained of the salient landmarks along the routes. This allowed for observations to be made on how the full set of features, identified in the first experiment, was narrowed down to the important ones for route descriptions in the second and third experiments. Additionally it could be deduced why a feature used in the route descriptions, generated in *Experiments Two* and *Three*, is salient to the participants by looking at how it was described during the first experiment. The routes were developed so that they were not visible from one another and so that the participants would end up in a location similar to where they started from. Finally, the routes were chosen to incorporate different areas of Edinburgh, such as the Royal Mile (a very tourist-centric area), the Grassmarket (which contains a large number of pubs, bars, and restaurant), Lauriston Place (containing a mix between residential and large public service buildings such as hospitals and schools), and Chambers Street (which has an education focus with museums and the buildings for the University of Edinburgh). This meant that the routes had a large amount and variety of salient features in the surrounding area with some sections of the routes having a larger number of features whilst other section had a limited number. Several test runs of the routes were undertaken when testing the experiments' methodology. This focussed on the length of the route and on whether the information recorded was appropriate for the subsequent analysis. This resulted in the length of the routes being shortened and adjusted to reinforce the differences in the amount of features along the sections of the routes.

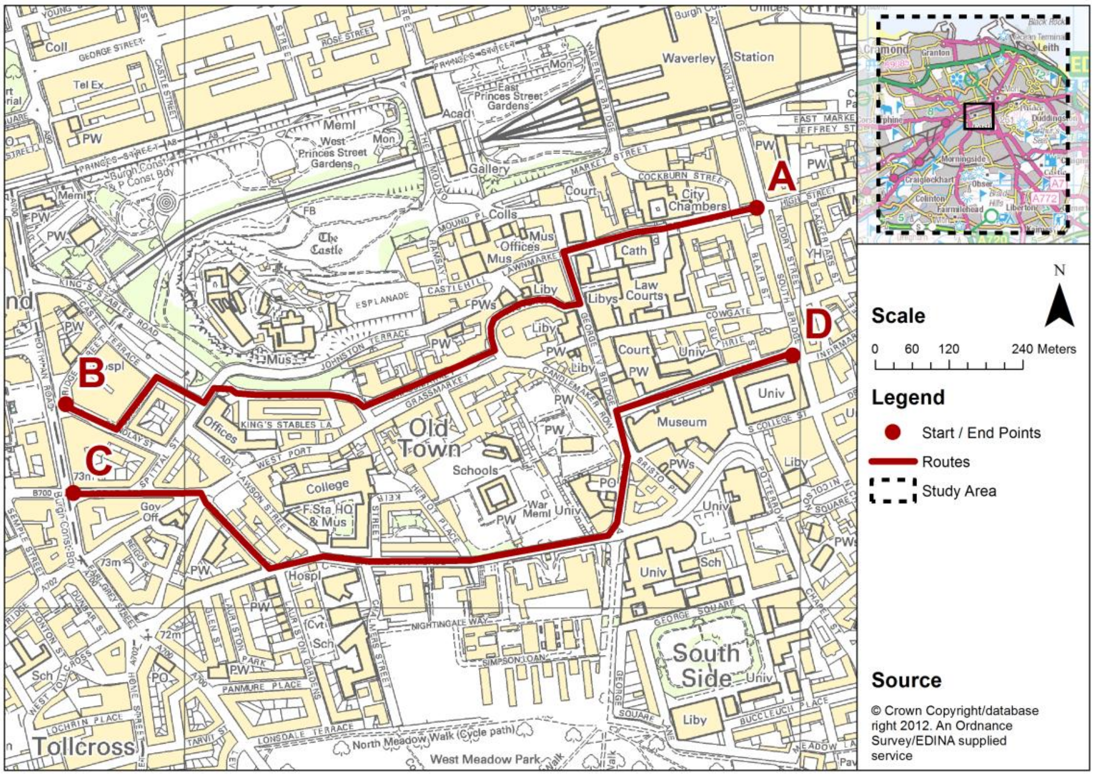


Figure 3.3: Illustration of the two routes: A-B and C-D. Route C-D is the simpler one

3.3.3 Participants

The participants were forty students from the University of Edinburgh, twenty males and twenty females. Their ages ranged from 19 to 31 with a mean age of 23 (Figure 3.4). There were 16 undergraduates, 18 master's students and six PhD candidates. Additionally, for seven participants, English was not their first language.

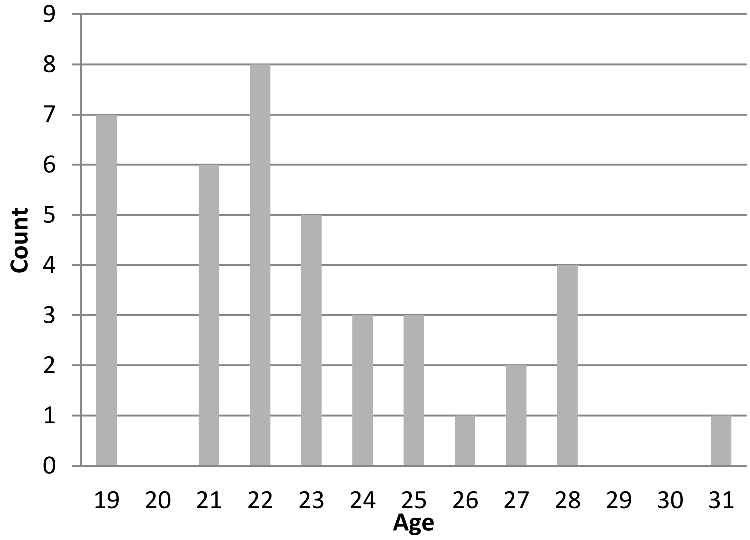


Figure 3.4: Participants' age ranges

The participants' length of residency in Edinburgh varied from four months to 11 years, with 30 percent having lived in Edinburgh for six months or less (Figure 3.5). The average residency in the city was just over two years. In 80 percent of cases the participant's length of residency is related to the degree towards which they are studying and how far into that degree they are, for example the twelve students that had lived in Edinburgh for less than six months were all MSc students on a one year course or first year PhD students. There was, however, 25 percent of participants that have lived in Edinburgh for more than three years, of these only four people have been living there for five years or more.

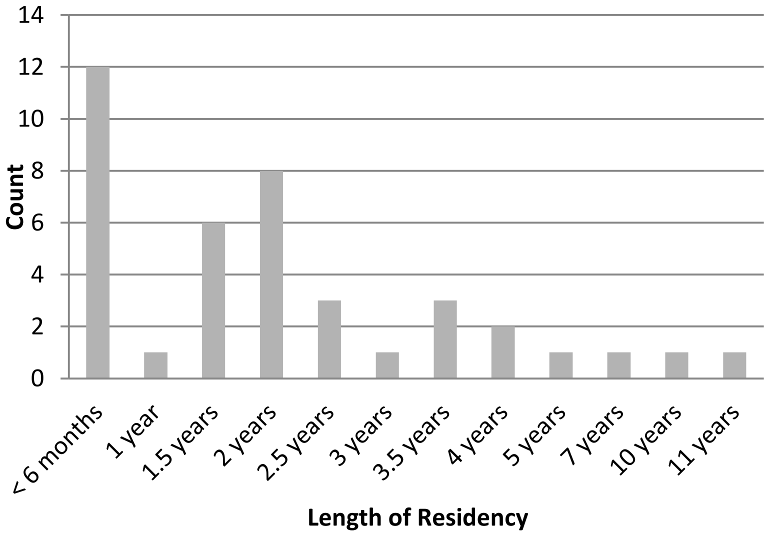


Figure 3.5: Participants' length of residency in Edinburgh, Scotland

3.3.4 Participants Familiarity with the Study Area

Familiarity is an important dimension of spatial cognition. Lynch (1960) concluded that the image of an environment is the product of the number and type of landmarks that exists within the environment (differentiation within the environment) and the number and type of past experiences that an individual has had there (familiarity with the environment). Whilst Mainardi Peron *et al.* (1990) stated that familiarity can be assumed to produce a facilitating effect on knowledge and the memorisation of places. Numerous studies have shown positive links between familiarity and the accuracy of the cognitive map (Hirtle & Hudson, 1991; Mainardi Peron *et al.*, 1990). In turn, studies have also shown that familiarity with the environment reduces wayfinding errors, thus enhancing wayfinding performance (Brill *et al.*, 1984; O'Neill, 1992).

Spatial familiarity with the environment, however, is a term which is poorly defined in the geographic literature. The notion of spatial familiarity underlies many social and behavioural constructs, especially with regard to the urban environment. Spatial familiarity can be assessed either subjectively by self evaluation or by observing the actions and behaviours of individuals (Gale *et al.*, 1990). Gale *et al.* (1990) identified four possible dimensions of spatial familiarity including locational knowledge, visual recognition, name identification, and interaction frequency. Interaction frequency is knowledge gained by close association due to the frequency with which you see, pass or visit the location. This was found to be the most distinctive behavioural dimension whilst the other three dimensions could be combined together to make a factual, cognitive dimension.

Within these experiments the participants' spatial familiarity has been measured through self evaluation and the participant's interaction frequency with the study area. The combined visual, name, and location dimension is not measured as part of this experiment as asking the participants distinct questions about the features of the environment prior to the experiments would have affected the results of the three experiments, whilst asking at the end of the study would have been affected by the participants recent interaction with the study area.

In order to measure the participant’s interaction frequency they were given an overview map of the study area (Figure 3.6) and asked to mark on it the areas which they knew well (frequently visit), the areas that they knew vaguely (infrequent visits), and those areas that they don’t know at all (never visit). Figure 3.7 illustrates two examples of the completed familiarity maps. Areas that the participants knew well are coloured blue, those area’s known vaguely are coloured red, and those areas that they do not know are coloured black. It was decided to use a three point scale for ease and quickness of coding the map.

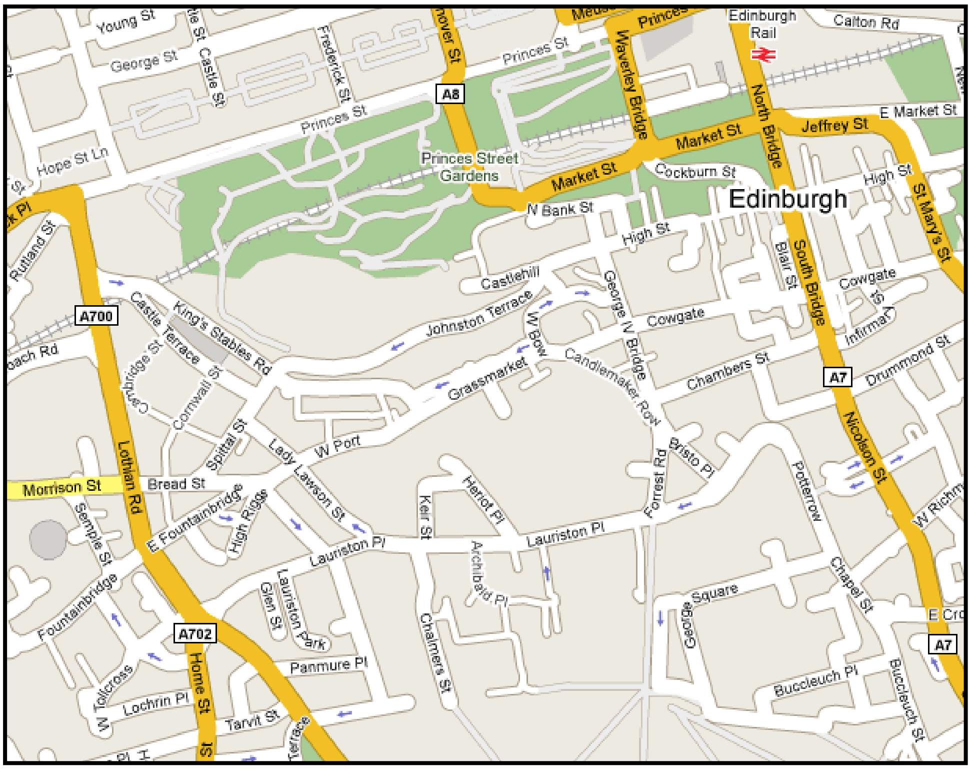
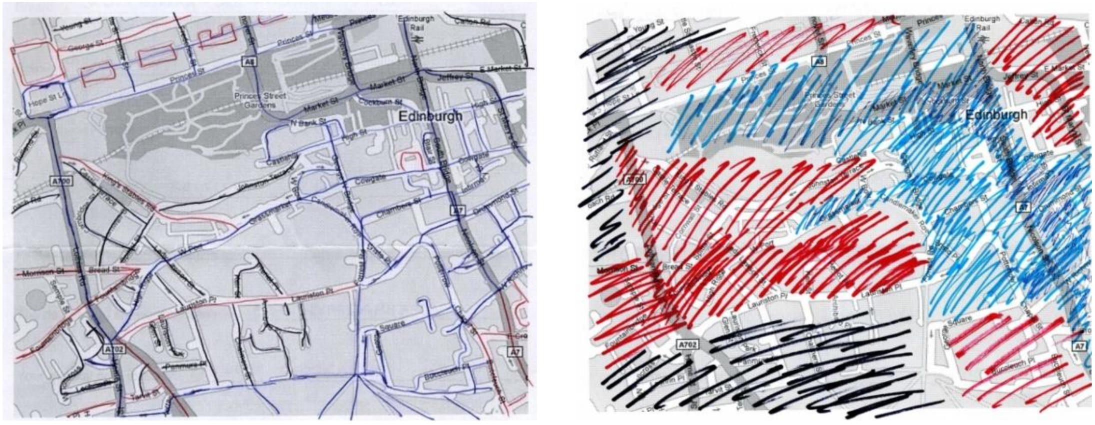


Figure 3.6: Map given to the participants to mark their interaction frequency (Google Maps, 2009)



(a) (b)

Figure 3.7: Two examples of a completed familiarity maps by participant's 4 (a) and 11 (b)

A total of 76 streets were selected from the map to look at a participant's familiarity (Figure 3.8). Each of the streets were measured in metres, with five streets split into two separate streets due to their length and differing levels of familiarity (Lauriston Place and High Street for example). For each participant, using their map as a base, each street was given a code of either familiar, vaguely familiar, or unknown which were assigned the values of 2, 1, and 0 respectively. These values were multiplied by the length of the street and totalled up to give a familiarity value. A value of 0 would mean that the individual didn't know any of the streets in question while a value of 338 represented that the individual was familiar with the entire study area.

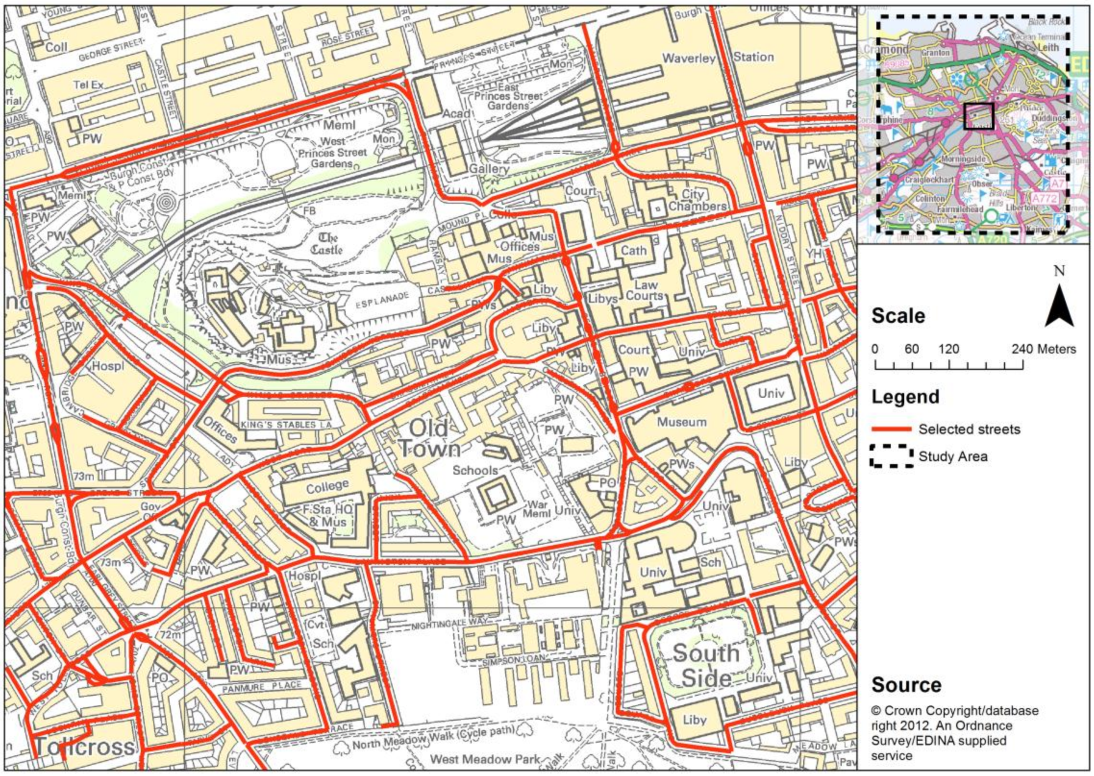


Figure 3.8: The 76 streets selected to measure participant's familiarity

The participants' familiarity with the study area ranged from 127 to 338.2, as shown in Table 3.1. This varied from one person who only knew 37 percent of the streets to two participants who knew the whole area extremely well. In general 70 percent of the participants were familiar or very familiar with the area. The implication of this high percentage of participants' familiarity with the study area is that the analysis will contain bias towards those features that the participants have existing local knowledge of and those they frequent often. The participants, therefore, may have already formed memories and associations with features along the routes. The participants may not be looking at the environment through 'new eyes' so they may be extracting the features that they know or are familiar with rather than those features that are most salient or most useful for navigation.

Familiar Ranking	Frequency of Participants	Percent
Very Unfamiliar	0	0
Unfamiliar	1	2.5
Vaguely Familiar	11	27.5
Familiar	16	40
Very Familiar	12	30
Total	**40**	**100**

Table 3.1: Level of participants' familiarity with the study area

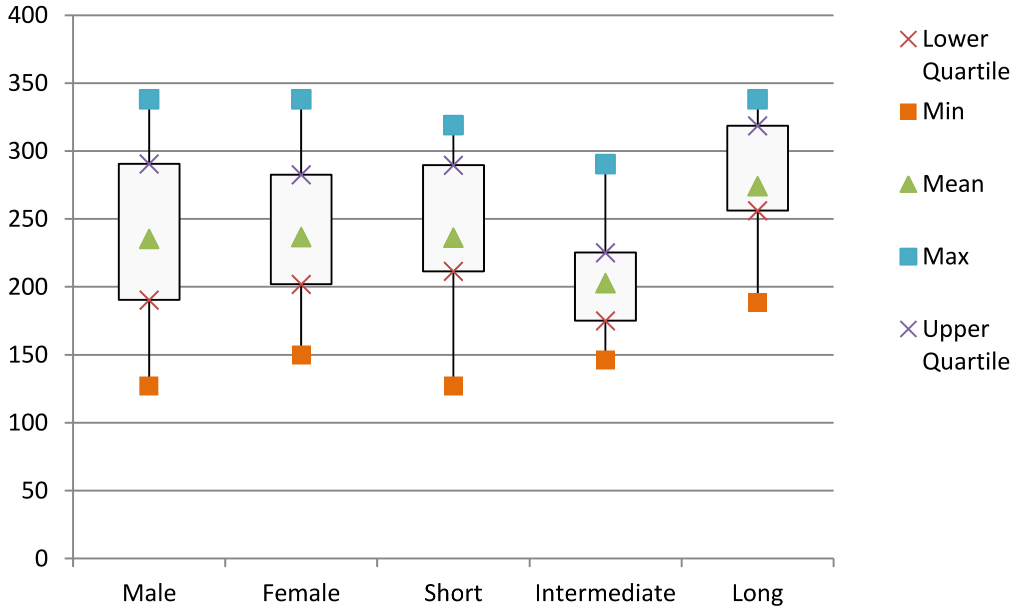


Figure 3.9: Spatial familiarity index by participants

The spatial familiarity index does not seem to vary significantly between the male and female participants, with both having an average familiarity of approximately 236, equating to familiarity with 70 percent of the study area (Figure 3.9). When looking at the length of residency, however, those participants with a long residency in Edinburgh (greater than two years) have a much higher average familiarity with the area than both those participants with short residencies (less than six months) and intermediate residencies (between six months and two years). Interestingly, those participants with a short residency have in general a greater familiarity than those with intermediate residencies. Investigating the relationship between the familiarity index and the participants' length of residency further shows that there is a slight positive correlation of 0.485, with this correlation being significant at the 0.05 level (Figure 3.10). This means that, to an extent, as a person's residency increases so does their familiarity with the area. This is a small positive value so based on the observations from Figure 3.9 it can also be hypothesised that when people are new to the area they immerse themselves in it and develop their cognitive map of the area quickly. This is especially true if they live within the study area as a number of the participants did.

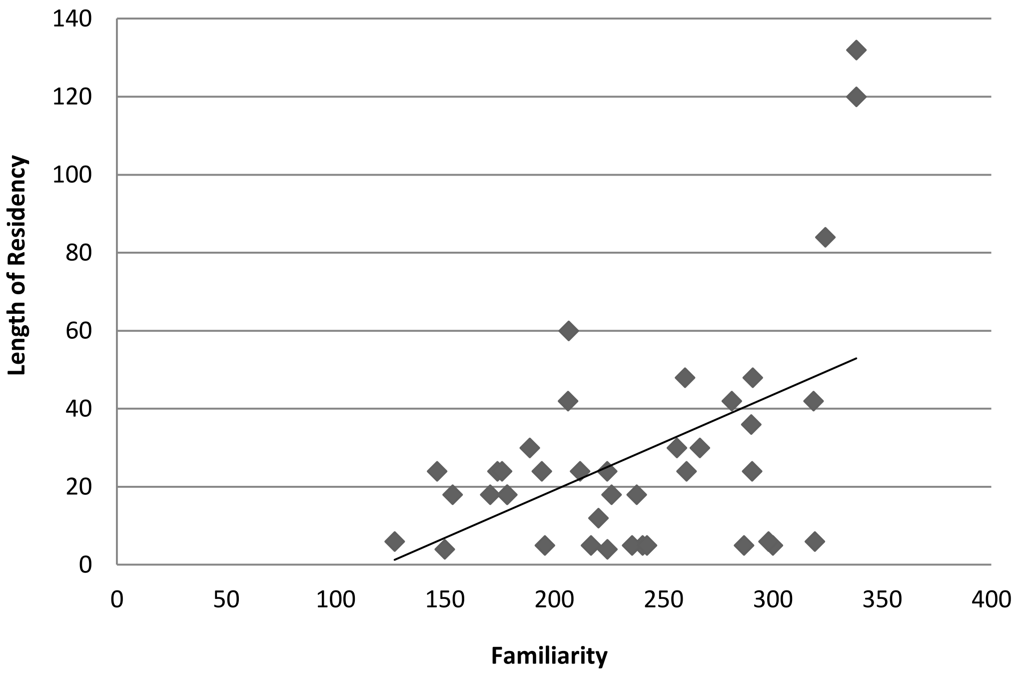


Figure 3.10: Graph showing the correlation between length of residency and familiarity

Both the length of residency and familiarity variables are used within the analysis of the third experiment (Chapter 5) to see if they are affecting the information about the route and its description that the participants are recalling from memory.

3.4 Summary

Chapter 2 explored the literature relating to use of landmark information in the provision of route directions. In addition to such previous research however, further empirical evidence was required in order to evidence the way in which individuals perceive urban space in order to undertake wayfinding activities. The findings of such research can then be used to inform the manner in which landmark information can be utilised in an automated system.

This chapter began by outlining the overall methodology undertaken within this thesis, discussing the three distinct stages of the research. The second part of the chapter introduced the landmark experiments and their methodology, along with an overview of the participants and the routes used. The chapter concluded with a discussion on the participants' familiarity with the study area. Chapters 4 and 5 discuss the findings of the landmark experiments in depth, as the findings from these experiments are crucial to the way in which landmark information is implemented in an automated system.

Chapter 4

Determining the Saliency of Landmarks

Few attempts have been made to define specifically how to measure a landmark's saliency. There are also questions regarding how best to identify and automatically extract features of interest from the environment, and how to classify and prioritize their use in formulating route descriptions. The experiments, outlined in the previous chapter and analysed in this chapter and the next, sought to provide answers to these questions. The experiments investigated the requirements for automating the inclusion of features of interest information within route directions, from determining the variables of saliency, the variety of features (i.e. buildings, monuments, streets) that need to be considered, and the location of where the references to these features should take place within the direction giving process.

The following sections discuss the results from the first of the three experiments introduced in Chapter 3. This first experiment set out to identify those features in the environment that stood out (were salient) to the participant and analysed the vocabulary used to describe them. The chapter proposes fourteen categories required to measure the saliency of features of interest. The automatic identification of the variables measuring the saliency of features within these categories are discussed in detail in Chapter 7.

4.1 Discussion on the Definition of Landmark

Participants were asked, individually, to provide a definition of what they thought a landmark was. This investigated whether or not the participants had any preconceived ideas about what constitutes a landmark. The definitions given varied greatly between participants, from very tight descriptions such as “a landmark is a noticeable building or statue” (Participant 18) or “a landmark is something that's historically or culturally important” (Participant 11) to very general definitions such as “a landmark is something that is easily separable from the surroundings and is something that is really distinct” (Participant 30) and “a landmark is something that sticks out as you walk past it and lodges itself in your memory, it can be anything from a rock to an impressive building” (Participant 32).

When looking at the definitions of a landmark the participants gave, there are a number of recurring ideas. Approximately 35 percent of participants stated that a landmark is something that stands out, i.e. is a feature that is distinctive or unique in some way. Whilst 25 percent of participants took this general definition of a landmark and clarified it further to include geography, that a landmark is something that distinguishes itself from the surrounding area (Table 4.1). This echoes many of the ideas discussed in the literature (Lynch, 1960; Sorrows & Hirtle, 1999). Overall, sixty percent of participants suggested that a landmark is a feature within the environment which is unique in its neighbourhood and easily separable from the surroundings.

The other most common features, noted by the participants, were that a landmark should be recognisable (22 percent), noticeable (20 percent), memorable (18 percent), and describable (10 percent) (Table 4.1). Individuals, therefore, should be able to easily recognise the feature no matter where they originate from or their familiarity with the area, and the landmark should be obvious and clear. A landmark should also be remarkable or impressive in such a way that it lodges itself into one’s memory and it should be easily describable, using only a few words. Finally, 15 percent stated that a landmark should be prominent within the view. Hence it should be sufficiently visible and people should be able to discern it immediately.

Definitions	**Percent**
Stands Out, Distinctive or Unique	35
Distinguishes itself from its surroundings	25
Recognisable	22.5
Noticeable	20
Memorable	17.5
Prominent within field of view	15
Describable	10
Used to navigate and orientate around	10
Has personal meaning	5
Permanent	5
Famous or Well Known	5
Historically and Culturally Important	2.5
Important Location	2.5
Prominent in landscape	2.5
Identifies a point in space	2.5
Has meaning to more than one person	2.5
Has a story behind it	2.5

Table 4.1: Participants' definition of a landmark

Some participants clarified their definitions by describing examples of what a landmark could be. Of these, 17 out of the 40 participants stated anthropogenic landmarks, such as buildings, statues, cathedrals, museums, libraries, car parks, public houses, bar, or restaurants (Table 4.2). Only two participants stated that it could potentially be a natural feature of the environment. Interestingly, ten participants stated that a landmark could be anything, referring to a landmark as any feature or object of the environment.

The majority of participants believe a landmark to be an anthropogenic structure, predominantly a building, which is distinct from the surrounding environment, and easily recognisable, noticeable and prominent within the field of view. Therefore, within any automated system it is important not to limit the landmarks to only buildings.

Landmarks can be:	Percent
Building	25
Anything	25
Statue or Monument	10
Shop	7.5
Castle	7.5
Natural Feature	5
Cathedral	5
Pub	5
Car Park	2.5
Restaurant	2.5
Theatre	2.5
Libraries	2.5
Museums	2.5
Sign	2.5
Structure	2.5

Table 4.2: List of examples of landmarks, as provided by the participants

Finally, a few participants described the different ways in which a landmark could be unique. Eight stated that a landmark should be relatively large in size, whilst three stated that it should differ in terms of colour. Other reasons put forward for a landmark being distinct included: being higher in the skyline, being well-known, being an abstract shape, and being permanent within the environment (Table 4.3).

Why	Percent
Big	36.4
Different Colour	13.7
Well Known or Famous	9.2
Up high (visible)	9.2
Big Sign	4.5
Abstract shape	4.5
Old	4.5
Small	4.5
Permanent	4.5
Isolated building	4.5
Striking	4.5

Table 4.3: List of example attributes that make a landmark unique, as identified by the participants

An overarching theme of the participants' definitions of what constitutes a landmark is that a landmark can be a variety of features; they are not just limited to being a statue or a building. As long as the landmark is easy to recognise, remarkable, easily describable, and prominent within the field of view, then potentially anything can constitute a landmark. It should be noted that Tables 4.2 and 4.3 might contain different landmarks and landmark attributes if the experiments were not focussed on a city centre. If it was a more residential area then more corner shops and housing might be included whilst if it was a rural setting then more features related to the natural environment could be expected to be incorporated. Some participants, however, did have a very narrow idea of what a landmark could be, therefore, from this point on landmarks will be referred to as *features of interest* to provide a much broader vision.

4.2 Experiment One: Saliency of a Feature of Interest

The objective of *Experiment One* was to investigate what makes a feature salient, from the viewpoint of the participants walking along a route. This experiment assessed the breadth of features deemed salient in the minds of the pedestrian as they walked through the environment, and analysed the vocabulary used to describe these features of interest. Although there is a theoretical understanding of saliency, there are relatively few empirical studies. A formal model of landmark saliency was proposed by Raubal and Winter (2002), which has been applied and refined in several subsequent studies (Klippel & Winter, 2005; Nothegger *et al.*, 2004; Winter *et al.*, 2004). Additionally Elias (2003a, 2003b) has identified a set of geometric and topological measures that relate to the saliency of buildings.

4.2.1 Features of Interest

The discussions recorded during the experiment were fully transcribed, resulting in a corpus of approximately 22,100 words documenting the discussions regarding the various features in the environments and the reasons as to why they ‘stood out’. From this corpus, the features that were acknowledged by the participants were identified along with the vocabulary used to describe them. The corpus was analysed with the help of Wmatrix, a web based software tool that allows for the analysis and comparison of corpuses, based on word frequencies and semantic meaning (Rayson, 2009).

A large variety of singular features (234 in total) were identified by the participants along both routes (Figure 4.1). An additional twenty generalized groups of features were also identified, such as "there is a bunch of pubs down the Grassmarket" (Participant 26) or "there are numerous monuments on the Royal Mile" (Participant 20). For the following analysis, the focus will be on the singular features that were identified by the participants.

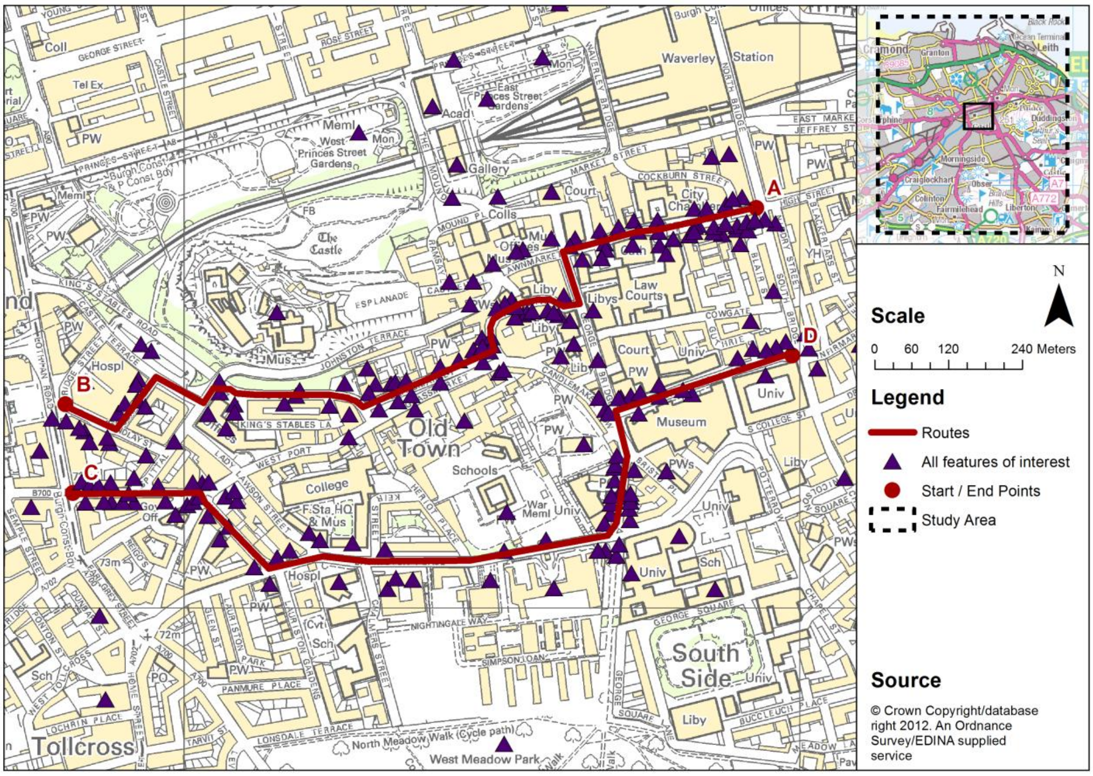


Figure 4.1: Map showing the locations of the features of interest that were identified by the participants in Experiment One

The features that were most often mentioned were buildings (66 percent), followed by streets (18 percent) and then statues and monuments (8 percent). The references to buildings within the corpus were generally related to either single occupancy buildings (such as the Museum of Scotland or the Apex Hotel) or were references to shops, restaurants, or bars that were located at the pedestrian level of multi storey buildings.

In total the 234 features identified were referred to 805 times within the corpus and of these, the twelve most frequently mentioned features accounted for 28 percent of the references (Table 4.4). This illustrates that these twelve are the important, key features within the study area. There were 92 features (or 39 percent of the features) which were only mentioned once. Edinburgh Castle was the most identified feature and received twice as many references as the next most identified feature, the National Museum of Scotland (Figure 4.2). This can be attributed to the fact that Edinburgh Castle is highly visible for the majority of route A-B, and is visible along two separate sections of route C-D. Interestingly, references were made to Edinburgh Castle even when it was not visible, illustrating that it is a well known feature within the landscape of Edinburgh. Edinburgh Castle was mentioned when participants were walking towards its general location, thus showing the Castle's role as a *global landmark* which helps to organize space and anchor individuals within it (Lynch 1960). Another possible global landmark within Edinburgh is Arthur's Seat – a prominent hill formed by extinct volcano in the centre of the city - however, whilst being visible for the majority of the second route it was only mentioned by two participants as a feature that stood out.

Feature	Number of References	Percent of Total References
Edinburgh Castle	58	7.2
National Museum of Scotland	26	3.2
Grassmarket area of the city	20	2.5
Royal Mile area of the city	17	2.1
Quartermile Development	16	2.0
Edinburgh College of Art	15	1.9
Bedlam Theatre	14	1.7
Greyfriars Bobby Statue	12	1.5
National Library of Scotland	12	1.5
Stereo Nightclub	12	1.5
St Giles Cathedral	12	1.5
Lyceum Theatre	12	1.5
Total	**226**	**28.1**
Overall References to Features	**805**	**100**

Table 4.4: The twelve most mentioned features in Experiment One

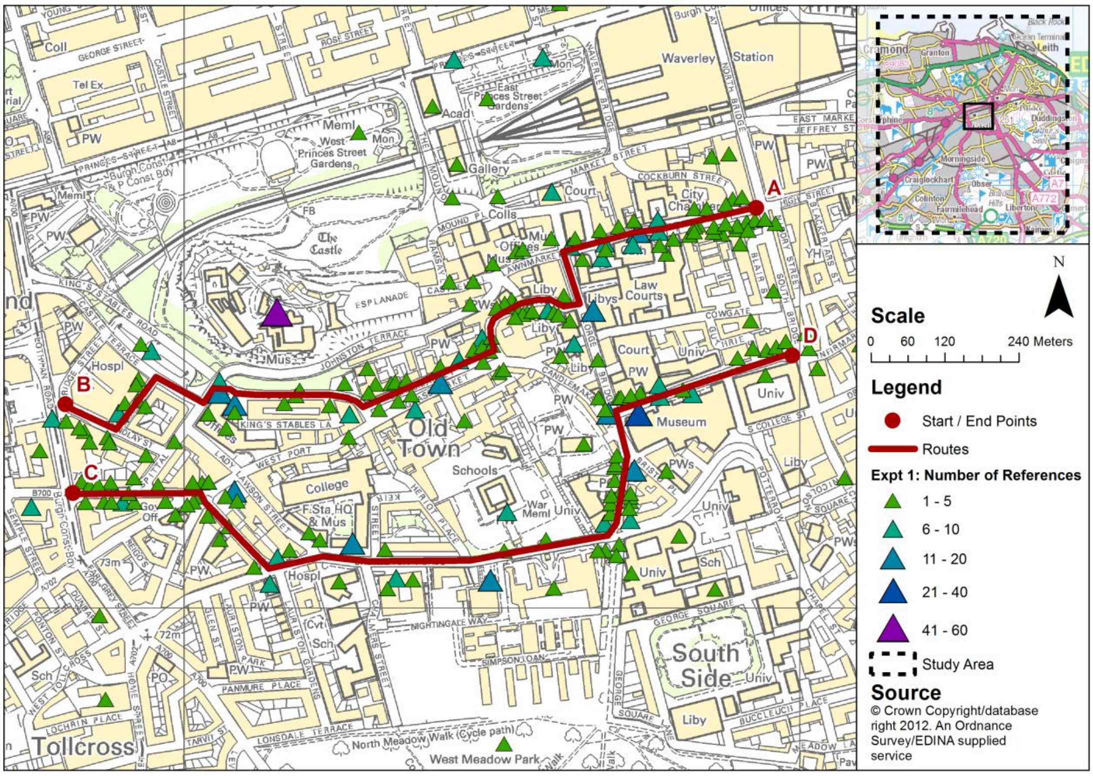


Figure 4.2: Map illustrating the number of references to the features of interest in Experiment One

Interestingly, it was not just that features that were visible that were identified and discussed. Whilst 218 (93 percent) of the features were along the routes, there were 16 features identified that were not visible. These features included the Scottish

Parliament, Cameo Cinema, the National Gallery of Scotland, and the suburbs of Newington and Portobello. These were generally mentioned and discussed if the route was heading in the general direction of the feature. These features were being included from the memory of the participants. For example one participant stated “I cycle down this road every Wednesday, it carries on down to Boots Chemist and the Cameo at the bottom” (Participant 6) whilst another said “the Scottish Parliament is right at the bottom of this road” (Participant 35).

A number of temporary features were also identified, some that were visible at the time of the experiments and others that were not. These included references to Edinburgh Fringe festival venues (such as the Underbelly) that are only in existence each August, the Farmer’s Market that occurs at Castle Terrace Carpark every Saturday and the Ice Rink in Princes Street Gardens that is there throughout December. Other temporary features such as building sites (such as the site of the new Missoni Hotel on the Royal Mile) and cranes were also identified by the participants. The cranes stood out as they were very visible on the skyline and were therefore acting as a temporary global landmark. The building sites stood out as they were stated to be ‘unusual’ and ‘imposing’. The following sections discuss the various characteristics of features that make them salient and the reasons why features were standing out in comparison to those around them.

4.2.2 Saliency of Features of Interest

The main objective of this first experiment was to clarify and order the reasons why a feature is salient. These were identified by extracting all the words and phrases relating to saliency from the corpus. This resulted in a set of approximately 350 different descriptors. These descriptors were then grouped together on the basis of similar meanings. For example descriptors such as ‘large’, ‘huge’, ‘small’ were grouped together under size whilst ‘brick’, ‘sandstone’, and ‘glass’ were interpreted to reflect the construction material of the feature. This grouping resulted in 14 saliency categories (Table 4.5). The most important of these are name, followed by size, age, and colour. Table 4.5 presents an overview of the identified saliency categories with examples of how they were mentioned within the transcriptions. The identification of each of these saliency categories are discussed in more detail in the following sections.

An important finding when investigating the saliency of features of interest, is that different groupings of features of interest (such as buildings and streets) have a different set of vocabulary used to describe features. For example, the size of a building may be large or big, whilst the size of a street might be wide or long. This is important as it has an effect on the development of the different measures of saliency. In effect, different variables will need to be calculated for different groups of features.

Additionally, the different saliency categories are interrelated. For example the colour of a building may be black but this may be attributed to both the condition and age of the building. For example Bedlam Theatre (a converted church) is often referred to as being ‘black in colour’, due to its age, and the condition of the church as “a bit grotty, it needs a scrub down” (Participant 29).

Saliency Category	Percent of References	Example Descriptors
Name	33.6	"Bedlam Theatre" "Lyceum Theatre" "Royal Mile"
Size	11.7	"St Giles, it's a large building on the left" "Grassmarket, the very wide pedestrian street" "Greyfriars Bobby, he is noticeable because he is so small"
Age	9.6	"Handsome old building behind the trees" "This is the new bank building"
Colour	7.5	"Yellow building which is quite striking in itself" "The blue police box is quite different"
Emotions towards Features	6.8	"I love this" "This is beautiful" "This is the most miserable place in Edinburgh"
Decoration and Signage	5.6	"The joke shop has a giant nose and glasses on it" "The Blue Blazer Pub is blue and it has the name in big gold letters"
Location	4.7	"It is on the corner" "It stands alone" "It is set back off the road"
Construction	3.8	"This stands out because it is enclosed in glass" "The street has become cobbled again"
Architecture	3.6	"St Giles Cathedral, its distinctive architecture, gothic" "Point Conference Centre looks a lot more modern than everything else"
Function	3.6	"Church" "Theatre" "Restaurant"
Shape	3.5	"It is quite unusual, cylinder shaped" "The curve and bend of Victoria Street"
Condition	2.5	"The broken windows on that church" "Lots of little potholes about this road"
Cultural & Historical	2.2	"Grassmarket is a well known, characteristic street in Edinburgh" "This is where the last hanging took place"
Temporality	1.4	"The Underbelly is here during the fringe" "The building site is not permanent"

Table 4.5: Fourteen prioritized categories of feature of interest saliency

It is also important to note that the saliencies of features, described along the route, were similar amongst the participants. For example, the Edinburgh College of Art was generally described as being 'big, red, new, and square' whilst the participants who described Bedlam Theatre always described it as a 'converted church' with 'big red doors at the front' (Table 4.6).

Edinburgh College of Art is:

- quite striking just because it has a flat top on it and its orange and the windows kind of remind me of a prison, they are narrow
- big red building, big square, it's quite hideous and nasty
- so square and blocky, looks like it's made out of Lego almost
- big red square and blocky
- a salmon colour which stands out from the crowd, and its newish looking, I think that is why it's kind of attracting my eyes, there is glass things on top and it has lot of windows
- it is another funny coloured building slightly more orangey than the rest

Bedlam Theatre is:

- really noticeable, it kind of looks like a gothic church at the moment because it is so black with a red door
- a old church converted into a theatre, it's sort of on the corner of a triangle, quite noticeable from lots of sides
- straight on in the middle of the road, with a huge big red door
- up ahead, its black again a different colour with the big red door
- nice as it's a theatre being in a church and being at the end point of the road, it's quite cool

Table 4.6: A subset of the descriptions provided for the Edinburgh College of Art and the Bedlam Theatre

4.2.3 Name Saliency

Name was included as a measure of saliency because it is important to recognise that the majority of features identified by the participants were mentioned by name before they proceeded to describe it. This symbolises that the features were easily and clearly identifiable, with names clearly labelling the feature. This also shows that even though saliency of features can be measured with a variety of measures when it comes to referring to it, it is most important that there is a clear name that can be associated to it. Name saliency has been deemed important from *Experiment One*, however this is affected by the participants familiarity with the area. The participants that are more familiar with an area are more likely to be able to correctly identify what a feature is or what function a building provides from their experience with the area. Their knowledge of the area in turn affects the way they name a feature. For example, in several instances the participants with a long term residency in Edinburgh referred to pubs, bars, and restaurants by previous names than what the current establishment is called. Additionally, there is also a contrast between the official names assigned to features and the vernacular names of features that are known by the general public. Individuals that are resident in the area longer are more often likely to use the vernacular or old names compared to what the current official name of a feature. A primary example of this is the reference to the road that makes up the Royal Mile which is actually a combination of five separate roads.

4.2.4 Size Saliency

Size can be the area, volume, or height of a building, the width or length of a road, or the size (large or small) of a statue. Raubal and Winter (2002) included size as façade area whilst Elias (2003b) used the area of a building. The majority of the descriptors, identified from the transcripts, related to features that were large in comparison to those features around it. These accounted for two-thirds of the mentions in relation to size. The most common descriptors for buildings were 'large', 'big', 'huge', 'massive', 'small', 'little', and 'wee' whilst for roads they were 'wide', 'long', 'narrow', and 'narrower'. There were only three descriptors for statues, 'big', 'small', and 'little' with small and little only being mentioned in relation to the Greyfriars Bobby dog statue (Table 4.7).

Example statements relating to size:

- "There is a large hotel in front of us, the Sheraton Hotel" (Participant 34)
- "George Heriot's School stands out because it is pretty grand" (Participant 8)
- "Grassmarket, the very wide pedestrian bit and there are lots of pubs" (Participant 16)
- "Greyfriars Bobby at the end of this street, he is noticeable because he is so small" (Participant 9)
- "Nice wee alley Grindlay Court" (Participant 10)
- "That tower is ridiculously tall, but I have never noticed it before" (Participant 30)

Table 4.7: Example statements relating to the size saliency measure

4.2.5 Age Saliency

Age is referred to generally as either ‘old’ or ‘new’. Raubal and Winter (2002) argue that age is part of the condition of a building. Ideas surrounding the age of features are very complex. Within central Edinburgh, it can be difficult to identify an old building from a new one. Buildings are often built to appear old, where as refurbishment of old buildings can give the appearance of it being newer than it is. The idea of what constitutes old varied between the different participants. For example some participants mentioned age in relation to ‘old Georgian buildings’ or ‘old Gothic buildings’ that are over 100 years old. Whilst buildings built more recently, such as The Blood Donor Centre, which was built in the 1960’s were also referred to as old. Additionally, if there was a shop or restaurant located within a building, it was the building as a whole that was use to determine age, rather than just the shop itself.

There were 19 different age descriptors identified within the analysis with the majority being versions of ‘new’ and ‘old’ such as ‘newer’, ‘newish’, ‘oldest’, ‘oldish’, and ‘older’ along with statements such as ‘looks new’, ‘old looking’, and ‘newish looking’. The two descriptors that weren’t versions of new or old were descriptors where the actual age of the building (1870 and 1953) were mentioned.

Age is primarily mentioned in relation to buildings, however, it was also mentioned with regards to statues. The statues of Adam Smith and James Braidwood located on the Royal Mile were mentioned as they were new at the time the experiments were conducted and many participants had not seen them previously (Table 4.8).

Example statements relating to age:

- “A new statue down there, James Braidwood” (Participant 35)
- “Then there is the new glass Quartermile building” (Participant 29)
- “There is a large new cream tiled building on our right” (Participant 34)
- “Handsome old church” (Participant 9)
- “Statue with a horse or something attached to it, its old and it’s a statue” (Participant 40)

Table 4.8: Example statements relating to the size saliency measure

4.2.6 Colour Saliency

Colour relates specifically to buildings, though it is rare that the building is the same colour across the entire façade. When the colour varies over the building it specifically relates to the colour of the building at pedestrian level. The colour mentioned by the participants could relate to either the colour of the construction material or the colour that the façade has been painted such as the Fringe Shop on the Royal Mile (Table 4.9, Figure 4.3). Edinburgh sandstone was a construction material commonly referred to and described as being red, pink, or salmon in colour. However, the colour of sandstone varies between quarries and in general is actually grey or buff in colour. These different interpretations make colour a difficult measure to automate. In a few cases, it relates to the colour of important features on the building such as the green copper dome on the Bank of Scotland Head Office and the building in which the Point Restaurant is located. Colour was included within the formal model of saliency put forward by Raubal and Winter (2002).

Example statements relating to colour:
- There is a yellowish building on our right, the Premier Inn
- Quite an old building, Blood Donor Centre, greyish, flat top, has four chimneys on the roof
- Art College, it really looks like an abandon factory, and it is red which in Edinburgh is really unusual
- Pizza Paradise on the other side of the road because its green
- The Fringe Shop always stands out because it is very colourful and just draws my attention
- There is a large new cream tiled building on our right which I think is a bank

Table 4.9: Example statements relating to the colour saliency measure

Figure 4.3: The façade of the Fringe Shop, Royal Mile

All of the pairs of participants mentioned that features stood out due to the colour with statements such as "it stands out to me because of the colour" (Participant 21), "it stands out because it is very colourful" (Participant 4), and "it stands out due to the colour apart from anything almost" (Participant 11). One participant even stated that "I'm a very colour oriented person; if it is a different colour I will remember it" (Participant 40). It was also often mentioned that some features did not stand out due to the colour allowing them to 'blend in' with their surroundings. These discussions show that colour is a very important visual saliency measure for individuals. Although care will be needed due to the variety of colours used to describe the same features, for example the National Museum of Scotland was described as sandstone colour, salmon, pink, and red as was the Edinburgh College of Art.

4.2.7 Emotions towards Features Saliency

Emotions towards features is a very interesting variable; one that is very subjective. All the participants expressed emotive responses towards features throughout the experiment. These feelings were both positive, such as "this building is absolutely beautiful" (Participant 31) and negative, such as "this building is really really ugly, it is a concrete 1960s type of building, it is hideous" (Participant 37).

For streets the emotions were often negative and associated with safety, especially for the female participants. For example, several female participants identified King Stables Road as an unsafe area stating that King Stables Road was "dark and secluded" (Participant 35) and "a negative place to go" (Participant 36). One even went as far as stating that

> "I always feel unsafe going up steps like this, I would probably find ways of not going up and down steps like this, they are a bit creepy. Because there is nothing around you feel isolated, certainly I would never come this way, I would avoid King Stables Road altogether" (Participant 35)

There were debates and contrary views amongst some pairs (Table 4.10) with one of the pair liking the feature whist the other disliked it. This suggests that there will be difficulty in modelling this aspect of saliency.

Person	Discussion
14	I love the towers up here on the building ahead I think its brilliant the way they have done it up and they have got the new and old mix on the buildings. I really like that
13	Really? The Quartermile stuff?
14	Yeah, you don't like that?
13	No I don't like it, why would you want a flat with a huge window?
14	I really like it, I love huge windows in buildings

Table 4.10: Example discussion on the differing emotions towards the Quartermile Development

4.2.8 Decoration and Signage Saliency

Decoration and Signage is similar to Raubal and Winter's (2002) idea of 'explicit marks' and refers to whether there is any unique decoration or signs on the feature, such as stained glass windows, a coat of arms, or the name of the restaurant or bar. It can also refer to the different decorations on a monument. For example, the Duke of Buccleuch Statue on the Royal Mile, was only identified by name by two participants, however, the six stags holding shields around the base of the statue were often described; "I can never remember who this statue is of, but I always remember the little stags" (Participant 21).

For buildings, signs showing the name of the feature were often pointed out, especially if the signage was different in some way. For example participants often mentioned the "creative signage to the Blood Donor Centre, the o's are replaced by hearts" (Participant 40). Other reasons included the size of the name signs such as "Point Conference Centre, the abnormally large letters just kind of jump out of you a bit" (Participant 17) or the colour of the sign "the Blue Blazer on the right, it looks like an older pub with gold lettering" (Participant 40). When referring to decorations and buildings it is when more than just the name of the feature is mentioned. For example "the chemist stands out with the sculpture of a chemistry bowl outside of it"

(Participant 5), "I always notice this place because of course there is a giant nose and glasses, it looks like a fun joke shop" (Participant 4) or "Crown Office stands out because it's got a crown shape railings at the top" (Participant 7) (Figure 4.4). For streets, however, no descriptors relating to decoration and signage were used by any of the participants.

(a) (b)

Figure 4.4: The decoration and signage measure of saliency: (a) Aha Ha Ha Joke Shop, Victoria Street; (b) Crown Office, Chambers Street

4.2.9 Location Saliency

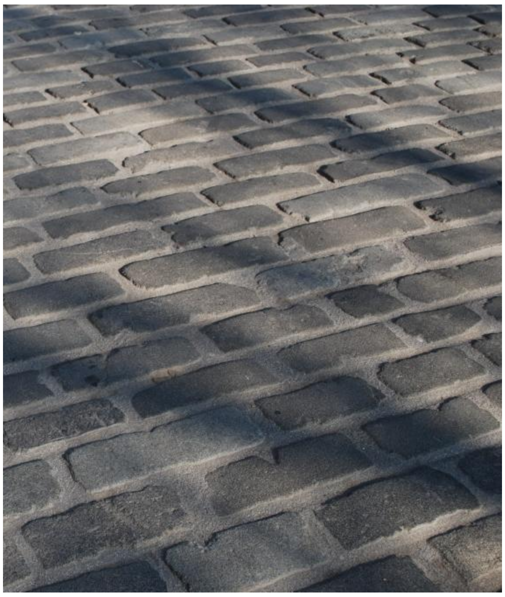
The location category aligns with the work by Elias (2003a, 2003b) and looks at the location of the feature in relation to decision points, in relation to the road or footpath, "the statue of William Chambers is in the middle of the road" (Participant 11), and in relation to other buildings, "George Heriot's School is surrounded by open space" (Participant 9). Other references to location included whether a building was 'set back' from the road, whether a building or statue was 'located on a corner' of a road, and whether a building was located 'on its own'. From a modelling aspect, it would therefore appear that there is a need to model the relationships between the feature and its immediate surroundings.

4.2.10 Construction Saliency

This refers to the construction material of the feature. In terms of a building, this referred to either the material of the entire building or the material of the façade. For example “it was a concrete 1960s type of building” (Participant 37), “the yellow sandstone building” (Participant 33), or “the glass-fronted theatre” (Participant 34) (Figure 4.5a). The construction material was also mentioned for distinctive features on a building, primarily domes. There were several of these domes situated on the routes and when mentioned they were always described as “green copper dome” (Participant 20).

For streets, however, the only construction material specified was cobbles, “the street is cobbled” (Participant 25) or “the streets become cobbled again” (Participant 33) (Figure 4.5b). This is a distinct feature of older cities and thus may not be applicable on a broader scale. The construction material was never mentioned in terms of statues.

(a)



(b)

Figure 4.5: Examples of the construction measure of saliency: (a) Quartermile Development (glass building); (b) Cobbles on the Royal Mile

4.2.11 Architecture Saliency

Architecture was only mentioned by participants in relation to buildings. It refers to the style of the building. Some of the different types of architecture identified within the study area included Georgian, Gothic, Modernist, Traditional, Minimalist, Classical, 1960's, and Art Deco. For example St Giles Cathedral was generally described as a 'gothic cathedral' whilst buildings such as the Quartermile Development and Point Conference Centre were identified as 'modern buildings' (Figure 4.6).

(a) (b)

Figure 4.6: Examples of the architecture measure of saliency: (a) St Giles Cathedral (gothic architecture); and (b) Point Conference Centre (modern architecture)

4.2.12 Function Saliency

Function or use can act as a proxy for the name of a feature, since certain uses can be inferred by looking at the features (especially restaurants, bars, hospitals, and schools). It can also reflect dynamic saliency, in that an inconspicuous building may be well known because of frequency of visitation.

4.2.13 Shape Saliency

Shape can refer to either the shape of a building, “the Museum of Scotland has a circular building on the corner” (Participant 11), or the shape of the road, “Victoria Street is a curvy street” (Participant 23) (Figure 4.7). Other descriptive words that were often used were ‘blocky’, ‘squarish’, and ‘domed’ for buildings and ‘bends’ for streets. Shape was not mentioned in relation to statues or monuments. Raubal and Winter (2002) calculated the shape factor of façades, whilst Elias (2003b) used variables such as the number of corners and elongation of the building form. More recently Musliman *et al.* (2010) used two measures of shape (volume and complexity) to model visual attraction.

(a) (b)

Figure 4.7: Examples of the shape measure of saliency: (a) National Museum of Scotland (circular building); (b) Victoria Street (curving upwards)

4.2.14 Condition Saliency

Condition is an interesting variable highlighted by this study, although it is a difficult variable to automate. It is a variable that has not been mentioned before in the literature as important to measuring saliency. Many participants, however, stated that buildings looked ‘abandoned and disused’ and pointed out broken or boarded-up windows (Figure 4.8). Other descriptors used to describe the condition of buildings included ‘tatty’, ‘worn’, ‘run down’, ‘grotty’, ‘grimy’, ‘falling apart’, ‘falling down’, ‘eyesore’, ‘neat’, and ‘shiny’. Negative descriptors were used most often to describe the condition of buildings with over 90 percent of the mentions relating to condition. For roads the only mention of condition was when potholes were observed.

Figure 4.8: Examples of the condition measure of saliency: Chalmers-Lauriston Church (abandoned with broken windows)

4.2.15 Cultural and Historical Saliency

Cultural and historical significance were both included within Raubal and Winter’s (2002) model of saliency, and they were also found to be important within this study. Participants spoke of historical events that had happened along the route such as “this is where the last hanging took place” (Participant 1) and on this basis stated that some of the features were more recognizable and well known than others.

In terms of cultural significance, a number of participants stated that George Heriot’s School looks like Hogwarts out of the Harry Potter books (Rowling, 1997). For example “this school is obviously Hogwarts, it takes my view all the time”

(Participant 30) and “this school here is like that one in Harry Potter” (Participant 32). Other cultural references included mentioning the iconic red telephone boxes, stating that buildings (such as the Edinburgh College of Art or Apex International Hotel) “look like they are made out of Lego” (Participant 11), and referring to Kings Stables Road as the scene of a murder in an Ian Rankin novel.

4.2.16 Temporality Saliency

Temporality of a feature received a number of references, generally related to construction sites and road works. This was especially true of construction sites with cranes, as these were very visible on the skyline. Several of the participants mentioned the location of a Farmer’s Market, that only occurs on Saturday. Additionally, there were a number of references to locations where Festival events would take place during the month of August, such as “the Underbelly is located there during the Fringe” (Participant 36) or “this building turns into a fringe venue” (Participant 5). This goes against the findings of Burnett (2000) who argued that the permanence of a feature is an important measure of saliency. This may perhaps be Edinburgh-specific, or at least specific to a city which puts a lot of effort into temporary structures erected for seasonal events primarily aimed at tourism. Possibly, for people that interact with Edinburgh frequently (such as the participants), these temporary features may stand out as being different from what they would normally see in that location. Therefore, their attention and interest is drawn to them more than if it was something that was viewed every day.

4.2.17 Reasons for Features ‘Standing Out’

In general, individuals mentioned that features ‘stood out’ because they were noticeable and unique. A key reason for stating why features stood out included ‘it just does not blend in to its surrounding’ or that ‘it is in contrast to the other buildings around’. Statements such as these reinforce the idea that saliency is not solely about what the feature looks like, but rather that the feature must be judged salient relative to its surrounding features (Lynch, 1960; Sorrows & Hirtle, 1999). It is clear that any automated system for describing saliency must take into account the relative nature of saliency, relative to other surrounding features.

Another reason why participants identified specific features was because they provoked a memory or connection with a famous icon. For example, references included police boxes that "look like a Tardis" (Participant 35) and a small gold statue that "looks like it is made out of Tunnock's Caramel Tea Cake foil" (Participant 11). Additionally, for the 15 participants who were born outside of the United Kingdom, many noted features stood out because they were culturally different. For example "we don't really have statues everywhere in Canada, so if I see a statue, I notice it" (Participant 4). A large number of participants also associated personal activities with particular features. For example, a couple of participants commented "I have acted in the Bedlam Theatre" (Participant 5) or "the university ball was held in the Apex Hotel" (Participant 24). Such observations are difficult to model in an automated context.

4.2.18 Modelling Summary

Fourteen categories have been identified from the experiment which illustrates the different ways in which features of interest are viewed as salient within Edinburgh. Methods are required for each of these saliency categories to automatically extract this information for the features of interest. A brief discussion follows on how this could be modelled, whilst a more detailed discussion is included in Chapter 7 on how they were developed for use within the pedestrian navigation system.

The preferred set of saliency measures includes both object-based measures as well as personal measures. Personal measures include categories such as emotions towards a feature and the condition of a building. These are difficult to calculate and incorporate into route directions as they represent the feelings and perceptions of an individual. These would require the development of egocentric methods to extract data from the individual. This information would include what features they feel positively (or negatively) about, or what do they perceive the condition of features to be. The incorporation of these saliency categories would allow for a highly advanced pedestrian navigation system capable of including features within route descriptions that are tailored to the needs and personal views of the navigator. The intention was not to use these saliency measures as part of the actual route instructions, rather they play a role in determine the saliency of features. A feature may be more salient if individuals have a high emotional response to it.

One of the important findings of *Experiment One* was that some saliency measures relate to only certain types of features, such as size relates to building, street, and statue features whilst architecture or colour only relate to buildings. Another important finding was within these saliency categories there were different variables that relate to specific types of features. For example, within the size category the variables for buildings include height, floor area, and façade area whilst for roads the variable could be width and length. Table 4.11 was distilled from the experiments, and lists a set of possible variables that could be recorded as part of the measurement of saliency.

Saliency Measure	Percent of References	Relates to	Possible Variables
Name	33.6	Building Road Monument	Name of company, restaurant, bar Name of Road Name of the Monument (or name of person the statue is of)
Size	11.7	Building Road Monument	Height, Area, Volume, Façade Area Width, Length Height
Age	9.6	Building Monument	Age
Colour	7.5	Building	Façade Colour
Emotions towards Features	6.8	Building Road Monument	Like the feature Dislike the feature
Decoration and Signage	5.6	Building Monument	Occupier Franchise Multinational Company (similar store fronts and signage)
Location	4.7	Building Monument	Location to the street Location to other buildings Location to decision points and/or corner
Construction	3.8	Building Road	Construction material Façade texture Cobbles
Architecture	3.6	Building	Architectural Style
Function	3.6	Building	Use Frequency of visitation
Shape	3.5	Building Road	Shape Complexity Shape Deviation (from a rectangle) Shape Deviation (from a straight line) Gradient
Condition	2.5	Building Road Monument	State of the Feature
Cultural & Historical	2.2	Building Road Monument	Famous/Well Known Tourist Attraction Listed Building
Temporality	1.4	Building Road	Festival Venues, Building Work Locations Road Work Locations

Table 4.11: A prioritised set of variables that could be used to measure the saliency of a feature

A number of these variables have been previously discussed within the literature and in a few cases attempts have been made to extract such variables automatically from datasets. This effort, however, has primarily focused on buildings, with little discussion of other classes of features. It is, therefore, important for the development of the pedestrian navigation system that the different types of features are taken into account and that the variables that measure their saliency are tailored towards each of them separately.

A number of ways can be envisaged by which these variables might be automatically extracted for the study area of the City of Edinburgh. For example, gradient could be calculated using a Digital Terrain Model (DTM) and a roads dataset, with the height of the start and the end of the road and its length, being used to calculate the gradient. The DTM could also be used to generate the height of buildings, statues and monuments, along with the volume of a building. Data from Historic Scotland and the Gazetteer for Scotland could be used to find those features that are culturally and historically significant. For example, if a feature has been mentioned within the Gazetteer for Scotland it could be deemed to be of importance and the length of the entry could reflect how important it is. Additionally, image processing algorithms could be written to automatically extract the façade colour, decoration, signage, and building condition using Google's Street View imagery.

It is also necessary to note that some datasets that could be used within the analysis could fit into several different saliency categories. Historic Scotland's dataset of Listed Buildings identify buildings in Scotland that are of 'special' interest. The basis of this could be either historical or architectural, thus being applicable to the respective significance categories.

Among this preferred set of measures, some of these variables are not easily generated. Variables describing emotions towards features and condition would be very difficult to generate because of their subjectivity. These saliency measures very much reflect an individual's opinions which may be extremely varied around a single feature. For example, Bedlam Theatre is often identified as a "theatre in a nice, gothic converted church" (Participant 17) whilst others have stated "that Bedlam is a bit grotty and in need a good scrub down" (Participant 29).

The creation of measures to represent these saliency categories vary in difficulty (Table 4.12). The subjective categories, such as condition and emotions towards features, are extremely difficult to measure. However, the more geometric measures, such as size, shape, and location, are relatively easy to develop using available GIS software. The main requirement in the generation of these variable is the bringing together of a range of different requirements to provide a complete view of the saliency of a feature.

Saliency Measure	Easy	Medium	Hard
Name	✓		
Size	✓		
Age		✓	
Colour			✓
Emotions towards Features			✓
Decoration and Signage		✓	
Location	✓		
Construction			✓
Architecture		✓	
Function	✓		
Shape	✓		
Condition			✓
Cultural & Historical	✓		
Temporality			✓

Table 4.12: An overview of the difficulty developing the measure the saliency of a feature

It is extremely important to stress that saliency is a relative measure. The feature must not be analysed by itself, rather it needs to be analysed in the context of its surrounding environment (Lynch, 1960; Sorrows & Hirtle, 1999). A number of authors have argued this point previously, and this study reinforces this argument. The method developed within this thesis for the determination of a features overall saliency and the selection of the most salient feature in the environment is discussed in Chapter 8.

4.3 Summary

The saliency of features can be measured in a variety of ways. In general, it must take into account the size, shape, and colour of the feature as well as its function.

Finally, the most important part of the saliency of a feature of interest is the fact that it must stand out from the surrounding area. It is therefore essential that the pedestrian navigation system incorporates a method to identify the most salient feature in relation to those around it for use at each possible decision point.

The data required to identify the features of interest and their associated saliency measures are outlined in Chapter 6 whilst the methods used to create the saliency variables and the development of the saliency model are discussed in detail in Chapter 7. The following chapter reviews the results of the second and third experiments which sought to identify those features most commonly used within route descriptions and within *on-the-spot* directions

Chapter 5

Investigating the Formation of Route Descriptions

Chapter 4 discussed the first experiment, which set out to identify those features in the environment that were salient to the participants. This chapter analyses the results of the second and third experiments. The second experiment explored the way in which route descriptions are formed when traversing a route, whilst the third experiment looked at the recollection of routes and the features of interest included within the short descriptions. The results from this chapter are used to inform the requirements for the pedestrian navigation system. It outlines what information is required to be presented within the route directions, at which location the features of interest should be included and identifies the large variety of feature types within the environment that need to be taken into account when determining which feature is the most salient.

5.1 Experiment Two: Developing the Provision of Route Directions

The second experiment explored how route directions were formed as the participants traversed the route. In particular, this experiment sought to identify those features used in the descriptions and where and when they were used in relation to the route. Several studies have looked to identify which landmarks should be used in route directions (May *et al.*, 2003; Sefelin *et al.*, 2005). Denis *et al.* (1999), for example, collected descriptions of three different routes in Venice and analysed the references to landmarks within them. Denis *et al.* found that there was a wide diversity of landmarks mentioned between the respondents. These could be divided into two categories: 2D horizontally extended entities (such as streets, bridges, and squares) and physical 3D objects (such as buildings). Denis *et al.* also found that the most frequently mentioned landmarks were ground-based entities (such as streets and bridges). This experiment follows on from that research, exploring factors governing choice, how and why they were referred to within route directions. From this, a classification schema of these features was formed, which allowed for the identification of all the feature of interest types that are applicable within route description and that are required to be modelled within the pedestrian navigation system. This experiment also provided information on the differences between simple and complex routes and identified the important points along a route where directions are required.

Experiment Two provided a very detailed set of descriptions that reduced down the large number of features that were mentioned in *Experiment One*, and allowed for examination of the reasons why certain features were selected more often than others, and how they were included in the descriptions (primary direction cues, confirmatory cues, or 'you have gone too far' cues). This provided a smaller set of the key features that the participants identified as being important to route directions.

The descriptions generated by each of the participants were transcribed and analysed using a standardized format based on the work of Denis and his associates (Denis, 1997; Denis *et al.*, 2001). Denis proposes that all statements can be simplified into minimal propositions and that these propositions can be placed within one of five categories:

1. Prescription of an action ('turn right')
2. Prescription of actions with reference to a feature/street ('turn right at the church')
3. Introduction of a feature/street ('there is a theatre on the left')
4. Description of a feature/street ('the theatre is red')
5. Commentaries ('you can't miss it!')

By simplifying the directions in this way, it was easier to identify the features referred to and to see how they were used within the directions (Table 5.1). Additionally, after simplifying the transcriptions into these minimal set of directions it was found that the majority of the references were related to features of interest (73 percent), rather than to streets (22 percent). These directions were related to an action, an introduction, or a description of a landmark confirming that features of interest are a more natural way to navigate by than street names.

Direction	**Proposition Category**
Veer left up Lauriston Street	Prescription of an action - Street
Past Church of the Sacred Heart	Prescription of an action - Feature
Go past the Novotel on the left	Prescription of an action - Feature
Past a Premier Inn	Prescription of an action - Feature
Go past the Fire Station on the left	Prescription of an action - Feature
Past the Hospital on the right	Prescription of an action - Feature
Past the Edinburgh College of Art	Prescription of an action - Feature
Arthur's Seat is in front of you	Introduction of a Feature
Past the Blood Donor Centre	Prescription of an action - Feature
Past the Building on the right	Prescription of an action - Feature
The Building is made of glass and is office space I think	Description of a Feature
George Heriot’s School is up ahead	Introduction of a Feature
Then past some apartments	Prescription of an action - Feature
The apartments are new	Description of a Feature
Past the Quartermile	Prescription of an action - Feature
Turn left by Starbucks	Prescription of an action - Feature
Bedlam Theatre is up ahead	Introduction of a Feature
The National Museum is up ahead	Introduction of a Feature
You are on forest road	Introduction of a Street
Go past Greyfriers Bobby	Prescription of an action - Feature
Turn right by the National Museum	Prescription of an action - Feature
Turn onto Chambers Street	Prescription of an action - Street
There is another Museum further down	Introduction of a Feature
Go past the William Chambers Statue	Prescription of an action - Feature
Go to the end of Chambers Street	Prescription of an action - Street

Table 5.1: Example classified transcription from Participants 1 and 2 for Experiment Two

Table 5.2 shows the breakdown of the propositions categories across the four separate routes. It illustrates how feature information was consistently more often referred to within the directions across all four routes rather than street information. It is noted that there is a larger variety of features along a route than changes in street name. Streets were primarily referred to when prescribing an action, whilst the introduction and descriptions of the street were relatively few. Features, however, were highly referred to across all three feature-specific categories. When a feature was mentioned (either in the prescription of an action or an introduction of a feature) it was occupied by a feature description 16 percent of the time for Route 1 A-B, and up to 22 percent of the time for Route 2 C-D (routes are shown in Figure 3.3). This supports the findings, from Chapter 4, that the name of a feature is the most important saliency category as this is how individuals refer to the feature, whilst only occasionally including additional information about the feature, such as its size or colour.

Direction	Route 1 A-B	Route 1 B-A	Route 2 C-D	Route 2 D-C
Prescription of an Action	2	8	6	6
Prescription of an Action - Feature	34	24	32	33
Prescription of an Action - Street	17	9	14	11
Introduction of a Feature	20	28	18	20
Introduction of a Street	2	4	4	3
Description of a Feature	16	20	22	21
Description of a Street	9	7	4	6
Total	100	100	100	100

Table 5.2: Breakdown of the proposition categories for each route (in percent)

5.1.1 Classification Schema for the Features of Interest

Both experiments revealed a breadth of features that 'stood out' from the environment. These features ranged in size from a plaque on a building, to something as big as a castle. There were 172 features mentioned overall in *Experiment Two*, 89 features along Route 1 and 83 features along Route Two. Five of these features were mentioned on both routes, so there were 167 unique features mentioned.

As identified in *Experiment One*, the variables of saliency relate in different ways to different features. Based on this knowledge, it was deemed important to investigate the different features of interest that were used within the route description gathered from *Experiment Two*. All the features, within the transcriptions, were identified and listed (with duplicated removed). Features were grouped together with other features of similar type. For example all the statues were grouped together, as were the natural features, buildings, and road features. Buildings and Connecting Features were then sub-divided based on the large amounts of features that were included within these categories. This resulted in a feature of interest classification schema (Figure 5.1). The spatial data used later in this thesis did not play a role in the development of this classification schema. When developing a pedestrian navigation system, all the features types identified within this classification schema should be incorporated. This additionally aids in the identification of the variables of saliency that relate to each class of features. It should be noted that this schema is not a complete set of feature types rather it has been gathered using all the features of interest that were referred to along the two routes used in the three experiments. It is noted in later chapters, that features such as water features and railways, which emerged as features of interest during the evaluation stage, are not currently accounted for by the schema in Figure 5.1.

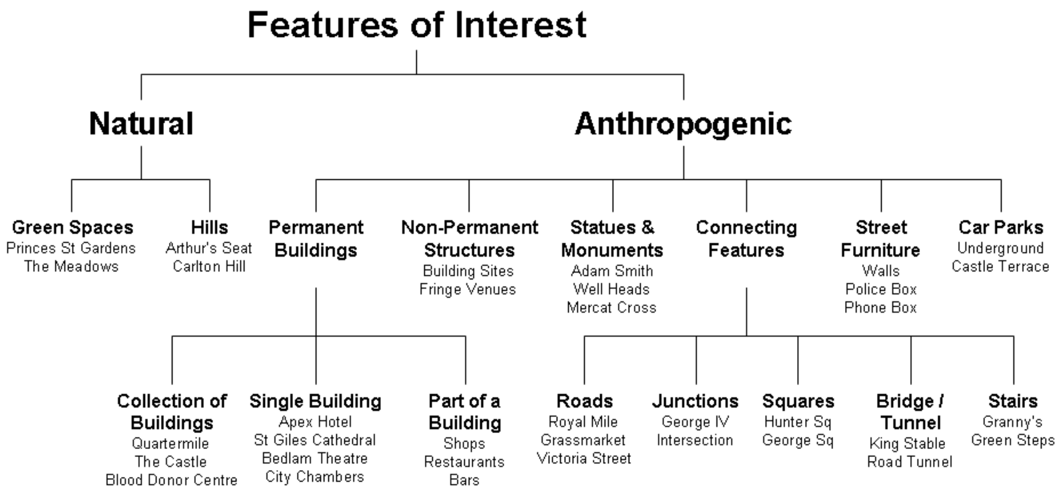


Figure 5.1: Classification schema for features of interest, with illustrative list of features

The classification category most widely referred to was *Single Building*, such as the National Museum of Scotland or the Edinburgh College of Art. This was closely followed by *Part of a Building*, which identifies the occupant of the building, generally at street level, such as Starbucks Coffee or the Blue Blazer Bar (Figure 5.2). Overall, the categories making up *Permanent Buildings* accounted for approximately 62 percent of the features mentioned in the experiment, whilst approximately 23 percent of the features mentioned were related to the *Connecting Features* categories (Table 5.3).

(a)

(b)

Figure 5.2: The Single Building and Part of a Building feature types (a) The Royal Lyceum Theatre (a single building) (b) Starbucks Coffee (part of a building)

Overall, the three most important categories are the same for *Experiment One* and *Experiment Three:* buildings (62 percent), roads and paths (12 percent), and statues and monuments (7 percent) (Table 5.3). However, this finer categorisation is important as it illustrates the large variety of features that are used when focusing purely on developing route directions. Each of these categories will have their own set of variables that measure their saliency. These will often be subsets of the saliency categories identified in the previous section. For example, the *Hills* could be measured using the name, size, and cultural and historical significance saliency categories whilst *Street Furniture* (such as telephone and police boxes) could be measured using the name, size, shape, colour, location, condition, and cultural and historical significance saliencies categories. It is important to take all possible features of interest into account when producing route directions. For example a statue may be in a more prominent position than a building, or a police box may signal a forthcoming turn better than a street. It will be necessary, however, to be able to compare the saliency across the different categories of features of interest.

Classification Category			**Total**	**Percent**
Natural	Green Spaces		1	0.5
	Hills		1	0.5
Anthropogenic	Permanent Buildings	Collections of Buildings	8	4.7
		Single Buildings	50	29.1
		Part of a Building	48	27.9
	Non Permanent Structures		4	2.3
	Statues and Monuments		12	7.0
	Connecting Features	Roads	20	11.6
		Junctions	10	5.8
		Squares	2	1.2
		Bridge/Tunnel	4	2.3
		Stairs	2	1.2
	Street Furniture		8	4.7
	Car Parks		2	1.2
Total			**172**	**100**

Table 5.3: Overall references to the different feature types in the classification schema

5.1.2 Minimal Set of Features

The features drawn upon in *Experiment Two* were generally a sub-group of the features that were identified in *Experiment One*. However, of the 162 there were 36 that had not been mentioned in *Experiment One*. Some of these differences can be explained by the fact that several features, which are composed of a number of buildings, have been divided into different features for part of this analysis. These included Edinburgh Castle, as different parts of the Castle are visible along both Route’s 1 and 2, and the Quartermile Development, which has two very distinct parts in terms of architecture that were being referred to separately (Figure 5.3). *Experiment Two* also has more street intersections mentioned than the previous experiment. Finally, there are approximately 20 new features of interest that were introduced during *Experiment Two*. These features included roads such as Castle Terrace and Lauriston Place, buildings such as Greyfriars Bobby Bar and The Lot (a bar), and street furniture such as no entry signs on the Grassmarket, the bus stop on

Castle Terrace, and the phone boxes on Grindlay Street. This shows that features that had not previously stood out during this experiment because of their use in helping to clarify the directions that were being given.

(a) (b)

Figure 5.3: The Quartermile Development (a) example of the period buildings (b) example of the modern buildings

For Route 1, a total of 89 unique features were mentioned, with 45 features mentioned in both directions of the route (A-B and B-A). Whilst along Route 2 there were 83 features mentioned, with 43 in common to both directions. Overall, features for Route 1 were mentioned 296 times, whilst Route 2 had slightly less features mentioned with 283 (Figure 5.4).

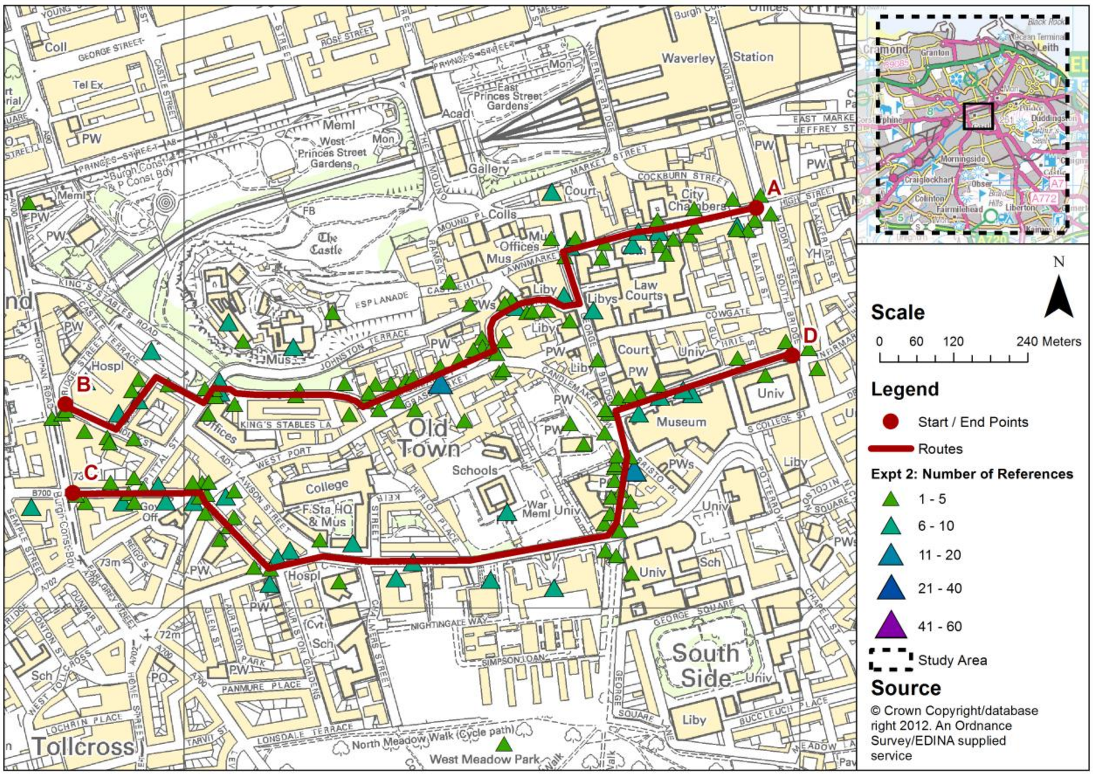


Figure 5.4: Map illustrating the location and number of references to the features of interest that were identified by participants in Experiment Two

These features can be reduced to a minimal set that are common to each route, based on those features that are mentioned most frequently within the descriptions (Table 5.4, Figure 5.5). By reducing the features to this minimal set, it can be seen that the major features with the experiment's study area are primarily related to the single building and road feature categories. Extending these minimal sets to incorporate the different directions of traversing the route, illustrates the importance of relative visibility within directions.

Route 1	**Route 2**
Edinburgh Castle	George Heriot's School
Grassmarket	National Museum of Scotland
St Giles Cathedral	Bedlam Theatre
Stairs on King Stables Road	Edinburgh College of Art
Castle Terrace Carpark	Novotel Hotel
Lyceum Theatre	Point Conference Centre
National Library of Scotland	Chambers Street
Victoria Street	
Usher Hall	

Table 5.4: Minimal set of features common for each route

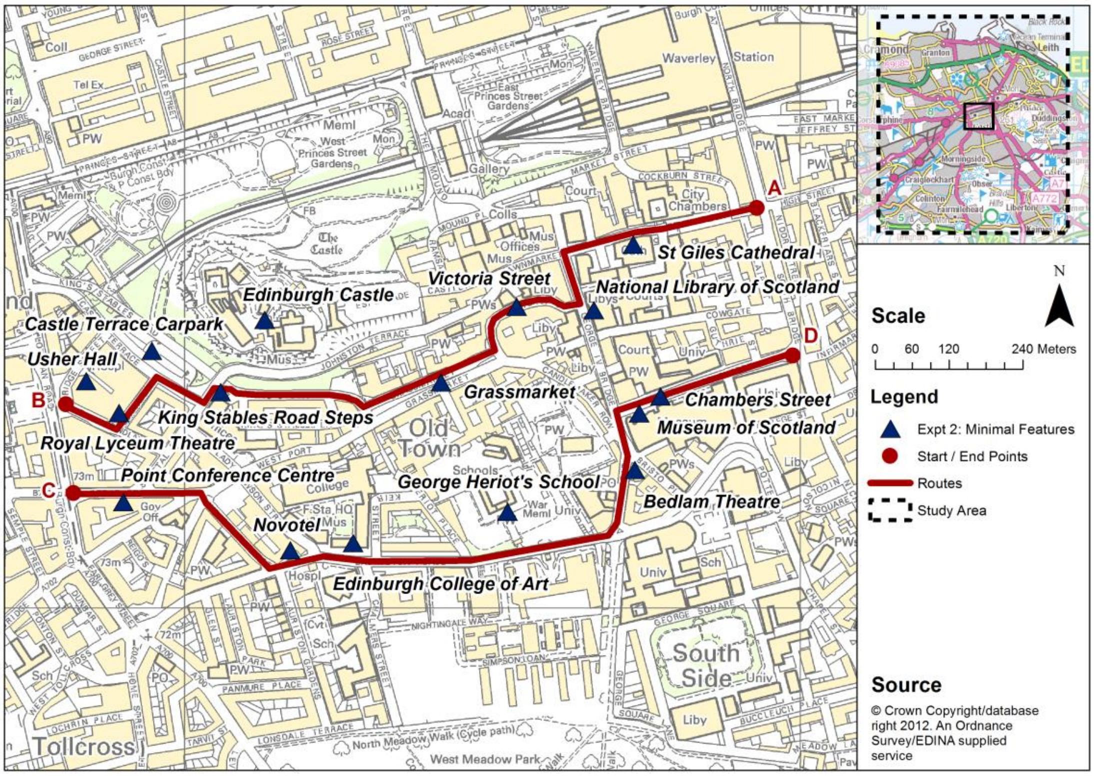


Figure 5.5: The location of the minimal set of features for each route

Different participants traversed each route in both directions (A-B, B-A, C-D, D-C). This resulted in each route having two core sets of features that were dependent on direction. Tables 5.5 and 5.6 confirm that direction of travel governs choice due to the visibility of the features as you approach them.

Route 1	
A-B	**B-A**
Edinburgh Castle	Edinburgh Castle
Grassmarket	Grassmarket
St Giles Cathedral	St Giles Cathedral
Stairs on King Stables Road	Stairs on King Stables Road
Castle Terrace Carpark	Castle Terrace Carpark
Lyceum Theatre	Lyceum Theatre
National Library of Scotland	National Library of Scotland
Victoria Street	Victoria Street
Usher Hall	Usher Hall
Building Works (Hotel Missoni)	
Cornwall Street	
Saltire Court Building (Cornwall Street)	
	Bank of Scotland Headquarters
	Companies House
	Apex International Hotel
	Granny Green Steps

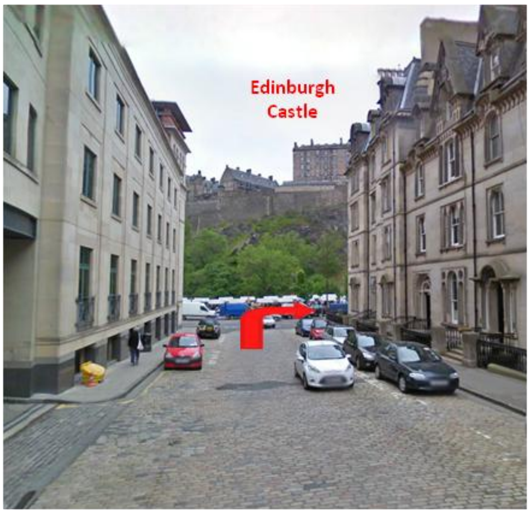
Table 5.5: Complete set of minimal features, relating to each direction, for Route 1

Route 2	
C-D	**D-C**
George Heriot's School	George Heriot's School
National Museum of Scotland	National Museum of Scotland
Bedlam Theatre	Bedlam Theatre
Edinburgh College of Art	Edinburgh College of Art
Novotel Hotel	Novotel Hotel
Point Conference Centre	Point Conference Centre
Chambers Street	Chambers Street
Blood Donor Centre	
William Chambers Statue	
Blue Blazer Pub	
Bread Street	
Doctors Pub	
Lauriston Street	
	Burke and Hare
	Point Restaurant
	Building Site on Lauriston Street
	Greyfriars Bobby

Table 5.6: Complete set of minimal features, relating to each direction, for Route 2

A feature may be more salient, and more visible, when approached from one direction than from any other. For example, the Saltire Court Building on Cornwall Street (which is new, orange, and located on a corner) is much more visible when approached on the route A-B. It occupies the majority of the view immediately in front of the participant, and it is located at a decision point. However, when walking the route in the opposite direction (B-A) it goes unnoticed by the participants, as they are walking alongside it and the directional change they need to make at this decision point is best defined by another feature (Edinburgh Castle) (Figure 5.6).

(a)



(b)

Figure 5.6: The different field of views for the approach to the decision point (a) from Castle Terrace (b) from Cornwall Street (Google Maps, 2012a)

Defining the most salient feature at a decision point depends on both the location from which you approach the point, and the direction in which you travel after the change of direction. A feature that is most salient for one orientation change may not be for other turns at the same decision point. This reinforces the view that saliency is relative both to other features in the field of view, and their degree of visibility (which in turn, depends on the direction of approach). Due to this variability of visibility, therefore, this thesis argues that visibility should be taken into account alongside saliency when developing the route directions to help determine which feature to use to direct an individual at a particular decision point. Therefore, not only do the relative differences between features need to be taken into account but the difference in the surrounding area approaching the feature of interest across the field of view must also be modelled in any automated system.

5.1.3 Complex versus Simple Routes

The two routes used in the experiments were designed to allow for the investigation into how the complexity of the route changed the information that was provided by the participants. Route 1 was the complex route whilst Route 2 was the simpler one. This complexity was based upon the number of reorientation points and possible reorientation points along the route, keeping the length of the each route approximately the same. Additionally, each route was walked in both directions (for example Route 1 was walked A-B and B-A).

The lengths of the directions generated by the pairs of participants varied greatly. The number of words ranged from 201 to 780 across the directions for each of the four walking routes, whilst the number of individual propositions ranged from 37 to 94 (Table 5.7, Figures 5.7 and 5.8). This reflects not only the individual style of the pair but in some cases reflects the pair's decisiveness. A number of the pairs with the smallest number for words and protocols would rework the directions after each reorientation point purposely to ensure that their directions were as simple and concise as possible.

	Route 1	**Route 1**	**Route 2**	**Route 2**
Direction	**A-B**	**B-A**	**C-D**	**D-C**
Features				
Number	69	65	60	60
No. Of Mentions	146	150	154	129

Table 5.7: Number of features mentioned, by route direction, in Experiment Two

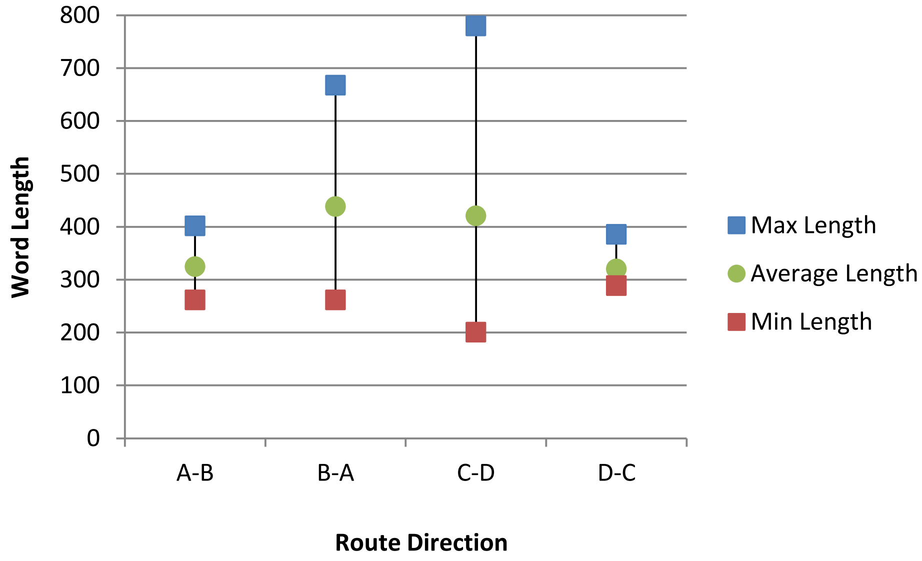


Figure 5.7: Direction word length, by route direction, in Experiment Two

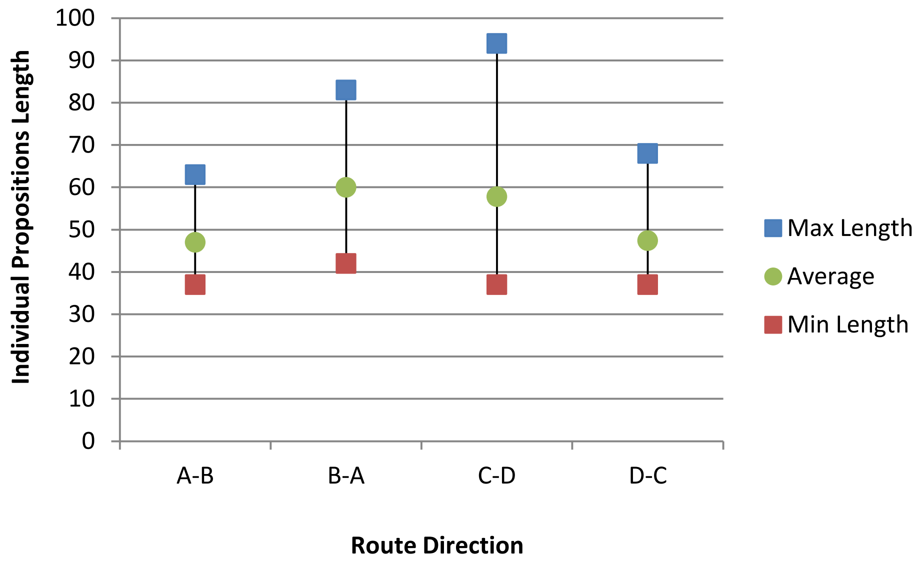


Figure 5.8: Individual proposition length (in words), by route direction, in Experiment Two

On average it looks like Route 1 A-B and 2 D-C are the easiest routes to describe, with these having the least number of average words and average number of individual propositions used. They also had the smallest ranges for both the number of words used (with 140 and 97 words respectively) and the number of proposition statements used, with 26 and 31 respectively.

It was expected that Route 1 would be described using a much larger number of words and proposition statements than Route 2. This, however, was not supported by the findings above. The number of features loosely supports the hypothesis with there being less unique features mentioned along Route 2 than Route 1. Route 2 C-D, however, has the most number of mentions of features within the descriptions. Again this is not what was expected. Therefore, based on the evidence from *Experiment Two*, there is no definitive difference between simple and complex routes when looking at the length of the directions and the features included. This means when developing an automated pedestrian navigation system, there is no requirements for the information presented in the route directions to differ between simple and complex routes. The idea simple versus complex route directions is also discussed in relation to *Experiment Three* in Section 5.2.3.

5.1.4 Types of Directional Cues

An important part of this experiment was to investigate the reasons why certain features were selected more often than others, and how they were included in the descriptions. For example, where they are used as primary direction cues, confirmatory cues, or 'you have gone too far' cues. Primary direction cues are when an action needs to occur along a route, such as a reorientation around a decision point, whilst confirmatory cues are cues that help ensure that the direction follower is still on the right path, to confirm that they are heading in the right direction. Within the directions both primary and confirmatory cues were widely used, however, you have gone too far cues were not mentioned at all. Primary cues accounted for a third of the statements in the directions compared to two thirds for the confirmatory cues across all four routes (Table 5.8).

	Route 1	**Route 1**	**Route 2**	**Route 2**
Direction	**A-B**	**B-A**	**C-D**	**D-C**
Primary Cue	38.2	32.7	29.6	27.6
Confirmatory Cue	61.8	67.3	70.4	72.4
Total	100	100	100	100

Table 5.8: Breakdown of the primary and confirmatory cues for each route (in percent)

To investigate the use of directional cues further, the proposition categories can again be utilised (Table 5.9). When looking at the use of primary cues, it can be seen that prescriptions of actions with regards to a feature ('turn left at the Museum of Scotland') are used more often than prescriptions of actions with regards to a street ('turn right onto Chambers Street'). Interestingly, confirmatory cues are much more prevalent for the prescription of feature actions ('you will pass the statue of Adam Smith') than primary cues, whereas they are much less important for the prescription of street actions.

Finally, the introduction of a feature ('there is the Blood Donor Centre') is much more widely used than the introduction of a street ('ahead is Middle Meadow Walk'). Both of these categories have been classified as confirmatory cues as they are identify features and streets along the route without making references to any action that is required.

		Route 1	**Route 1**	**Route 2**	**Route 2**
Direction		**A-B**	**B-A**	**C-D**	**D-C**
Action	Primary Cue	1.2	7	5.3	3.5
	Confirmatory Cue	0	3.3	2	3.5
Action - Feature	Primary Cue	19.4	15.4	12.1	14.1
	Confirmatory Cue	27.6	21	33.5	31.2
Action - Street	Primary Cue	17.6	9.4	12.1	10
	Confirmatory Cue	5.3	2.8	6.8	5.9
Intro. of a Feature	Confirmatory Cue	26.5	35.5	25.3	28.2
Intro. of a Street	Confirmatory Cue	2.4	5.6	2.9	3.6
Total		100	100	100	100

Table 5.9: Breakdown of the primary and confirmatory cues by proposition category for each route (in percent)

When participants were asked to develop directions as they traversed a route, they used a variety of information to supplement the core directions. The core directions generally contained more references to feature of interest information than to street information, however street information was still an important part. The streets that were most often referred to were the well-known streets along the routes, such as the Royal Mile, the Grassmarket, and Chambers Street. The lesser known streets such as King Stables Road, Lauriston Street, and Forest Road gathered minimal mentions.

This supports the findings from *Experiment One*, in that streets should be considered as a feature of interest in their own right, and their saliency variables should be calculated in the same manner all other features of interest. This will result in the key streets in Edinburgh still being used within the route directions.

Table 5.9 also illustrates that the use of features as confirmatory cues, within directions, is of high importance. The majority of information (approximately 55 to 60 percent) included in the directions were confirmatory cues, which referenced features of interest. It is also interesting that confirmatory cues were consistently used along the route, not just on the longer sections as would have been expected. The longer sections of the route did have more confirmatory statements, used especially if there were a set of large, distinct buildings along the section as was the case with Lauriston Place (475 metres in length). However, shorter sections such as the 85 metre section of George IV Bridge often had confirmatory references to features such as the construction site (now Hotel Missoni), Bedlam Theatre, and the Central Library. Thus it is important that the pedestrian navigation system should not only include the primary cues along the route, but should also include confirmatory cues that reference features of interest between the main decision point, to help facilitate more natural route directions and to ensure the individual that they are on the right track.

5.1.5 Modelling Summary

The previous four sections have identified a classification schema for features of interest, investigated the reasons why certain features were selected, looked at the differences between complex and simple routes, and discussed the importance of primary and confirmatory cues. All of these help inform the requirements for the development of the pedestrian navigation system.

The studies have shown that there is a great deal of variety in features of interest that can be used as directional aids within route directions. These features can be split between fourteen different classes (Figure 5.1). For each of the identified classes, there is a different set of variables required for modelling their associated saliency, as identified in *Experiment One*.

The most important facet of the saliency of a feature of interest is the fact that it must stand out from its surrounding area, requiring development of methods to select the most salient feature at each possible decision point. It was found during this experiment that whilst a large number of features can be used to give directions, it was possible to identify a core set that were used by 50 percent or more of the participants. The participants traversed the two routes in both directions (A-B and B-A) thus each route had two core sets of features. This is an important observation. It illustrates that saliency is relative to other features in the field of view, and their degree of visibility from the decision point, which will be different depending on the direction of travel. Therefore, the relative differences between features need to be taken into account (for example buildings' façade colours may differ around a decision point). The difference in the surrounding area approaching the feature of interest on either side must be modelled in any automated system. Additionally, visibility analysis is an integral part of any route giving system. Whilst the results discussed are for Edinburgh, a feature-rich urban environment, the saliency measures identified could be applied to a variety of settings from cities to rural locations. Additional research would be required to establish the different weights priorities and the importance of different feature types before the measures could be applied to different environments. Further work would be required before ideas identified from this thesis could be applicable to other contexts, such as rural areas.

5.2 Experiment Three: The Route Summaries

Finally, the third experiment looked at the recollection of the routes that were walked during *Experiments One* and *Two*. The participants were asked, individually, at the end of each experiment to provide a set of directions for the route that they had just walked from memory. This provided an insight into which features of interest the participant would choose if required to give a quick set of directions to someone. It also enabled identification of those features that were most memorable. As with *Experiment Two* the descriptions generated by the participants were transcribed and analysed using a standardised format of minimal propositions based on the work of Denis (Denis, 1997; Denis *et al.*, 2001). Table 5.10 shows an example of transcriptions of the type of features and their descriptions used within the route directions for *Experiment Three*. Several of the features mentioned in the example route direction are illustrated in Figure 5.9.

Description
Walk up Chambers Street
Past the Royal Museum
Past the National Museum of Scotland
The National Museum is a round red building and quite new
Turn left
Face the church
The church is old looking and is dark with red doors
Stay on the right side of the church
Walk down the street
The street is short
Turn right
Continue straight
You will go past a school
The school is a big huge building and looks like a small castle
Continue straight for a long time
The street bends
Veer to the left where the road bends
Turn right when you get to the Premier Inn on the right side
Walk until you come to the construction site
See the Nail Polish Bar
The Nail Polish Bar is purple
Take the second road to the left
Continue straight
Keep walking until you reach the Odeon

Table 5.10: Example route directions from Participant 19 for Experiment Three, using Route 2 D-C

(a) (b) (c) (d)

Figure 5.9: A selection of the landmarks used in the description in Table 5.10 (a) National Museum of Scotland (b) Bedlam Theatre (c) George Heriot's School (d) Construction site

5.2.1 Features of Interest

Overall, 187 unique features were identified during *Experiment Three* (Figure 5.10). This is less than the 234 features that were mentioned during *Experiment One*, however interestingly, is more than the 167 features that were used within the directions in *Experiment Two*. This shows that memory of the route and existing knowledge of the study area played a key role when the participants are asked to generate the directions. When breaking the features down, 106 features were mentioned in relation to Route 1, 56 of which were common to traversing both directions of the route (A-B and B-A). For Route 1 A-B there were 22 unique features mentioned, whilst Route 1 B-A had 28 unique features (Table 5.11). On the other hand, Route 2 had 81 features mentioned, with only 39 being common to both directions. For Route 2 C-D and Route 2 D-C there were 19 and 23 unique features mentioned respectively (Table 5.11).

	Route 1	Route 1	Route 2	Route 2
Direction	**A-B**	**B-A**	**C-D**	**D-C**
Number of Features	78	84	58	62
Number of Mentions	310	299	285	260
Number of Unique Features	22	28	19	23

Table 5.11: Breakdown of the features mentioned in Experiment Three

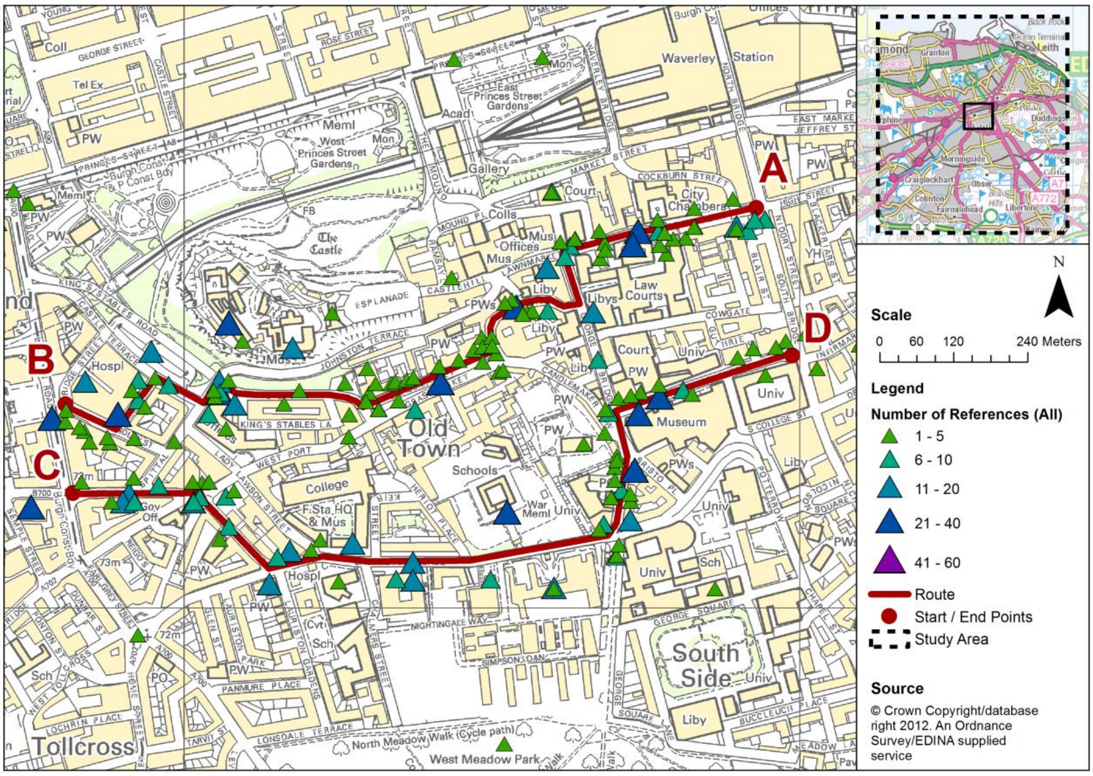


Figure 5.10: Map illustrating the location and number of references for all features of interest identified by participants in Experiment Three

Of the 106 features mentioned for Route 1, 80 percent of them fell into four of the categories identified in the classification schema (Figure 5.1); part of a building (29 percent), single building (23 percent), roads (17 percent) and statues and monuments (11 percent). Whilst for Route 2, three categories represented 84 percent of the features mentioned; single building (34 percent), part of a building (30 percent), and roads (20 percent). As buildings, streets, and statues and monuments have consistently been the most referred to features it is important throughout the three experiments, they are the features that are focussed on when developing the saliency measures in the following chapter.

The features mentioned can be reduced to a minimal set for each route based on features that are mentioned most frequently (over 45 percent) within the descriptions (Tables 5.12 and 5.13). For Route 1 Edinburgh Castle has been recorded as two separate features as it is visible along the route in more than one location. It is visible from King Stables Road where the participants can see the Great Hall building and also from Castle Terrace where the participants can see the New Barracks building.

This minimal set, once again demonstrates the effect that the different directions of traversing a route has on the features that are drawn from the environment. For example, the Grassmarket and the Royal Mile would be included in descriptions for Route 1 walked in both directions, however, the differences arising in relation to the direction a route is walked are very obvious when you see that features such as the National Library of Scotland, Companies House, and Victoria Street are much more obvious when traversing the Route B-A than A-B (Table 5.12, Figures 5.11 and 5.12).

	Route 1	**Route 1**	
Direction	**A-B**	**B-A**	
Feature of Interest	**(percent)**	**(percent)**	**Difference**
Grassmarket	90	95	5
Royal Mile	90	85	5
Stairs on King Stables Road	80	65	15
Usher Hall	45	30	15
Lyceum Theatre	55	85	30
National Library of Scotland	35	65	30
St Giles Cathedral	75	40	35
Castle Terrace Carpark	65	25	40
Starbucks (Royal Mile)	65	25	40
Companies House	5	45	40
Victoria Street	45	85	50
Edinburgh Castle (King Stables Road)	70	15	55
Edinburgh Castle (Castle Terrace)	35	90	55

Table 5.12: Complete set of minimal features for each direction for Route 1 in Experiment Three

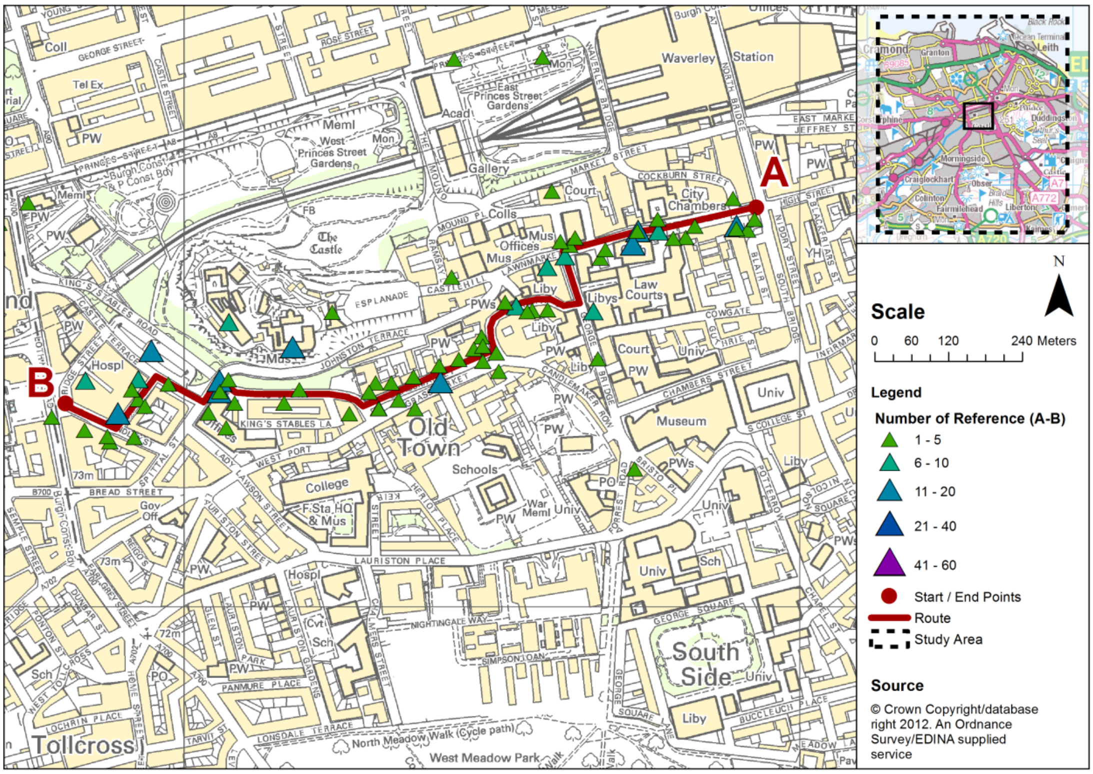


Figure 5.11: Map illustrating the location and number of references to the features of interest that were identified by participants in Experiment Three for Route A-B

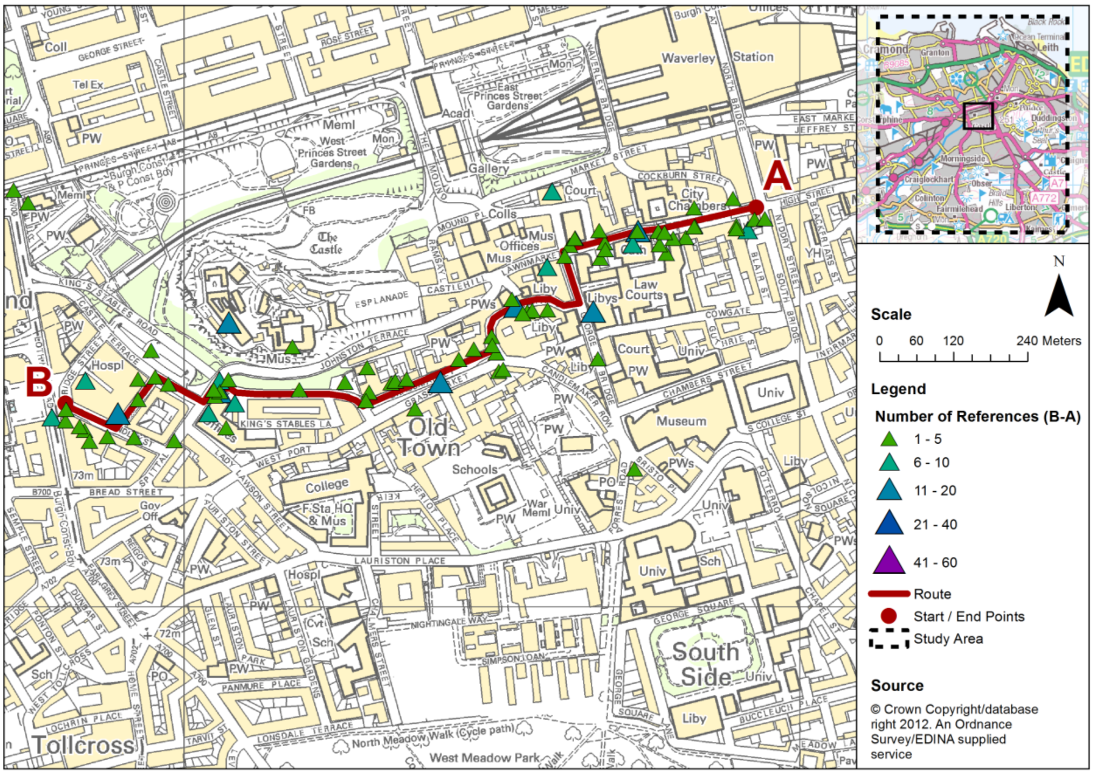


Figure 5.12: Map illustrating the location and number of references to the features of interest that were identified by participants in Experiment Three for Route B-A

Features such as George Heriot's School, Chambers Street, and the National Museum of Scotland are very highly referenced in the descriptions for both directions of traversing the Route 2. But again, the differences are very obvious with Bedlam Theatre and Odeon Cinema being used more often on Route 2 D-C whereas Doctors Pub and Bread Street are mentioned more on Route 2 C-D (Table 5.13, Figures 5.13 and 5.14).

	Route 2	**Route 2**	
Direction	**C-D**	**D-C**	
Feature of Interest	**(percent)**	**(percent)**	**Difference**
Edinburgh College of Art	45	45	0
Novotel Hotel	45	45	0
Chalmers-Lauriston Church	50	40	10
George Heriot's School	80	95	15
National Museum of Scotland	80	65	15
Chambers Street	80	100	20
Blue Blazer Pub	45	5	40
Odeon Cinema	40	80	40
Bedlam Theatre	50	95	45
Forest Road	50	0	50
Doctors Pub	60	5	55
Bread Street	70	10	60

Table 5.13: Complete set of minimal features for each direction for Route 2 in Experiment Three

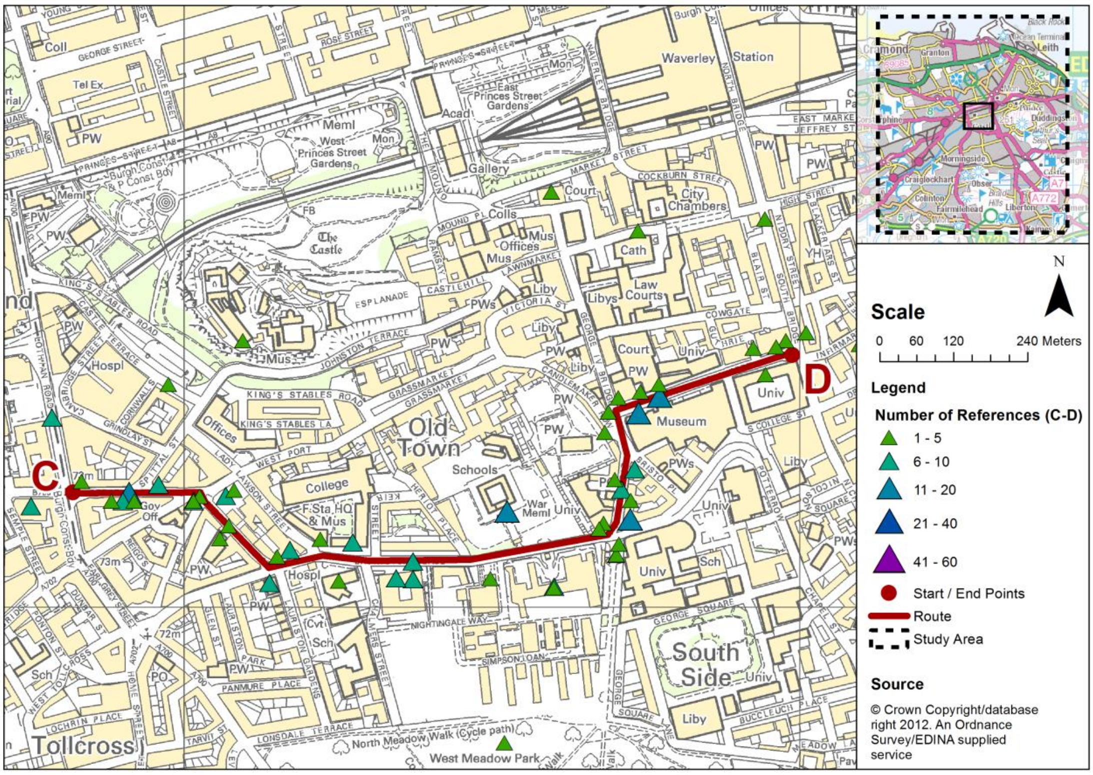


Figure 5.13: Map illustrating the location and number of references to the features of interest that were identified by participants in Experiment Three for Route C-D

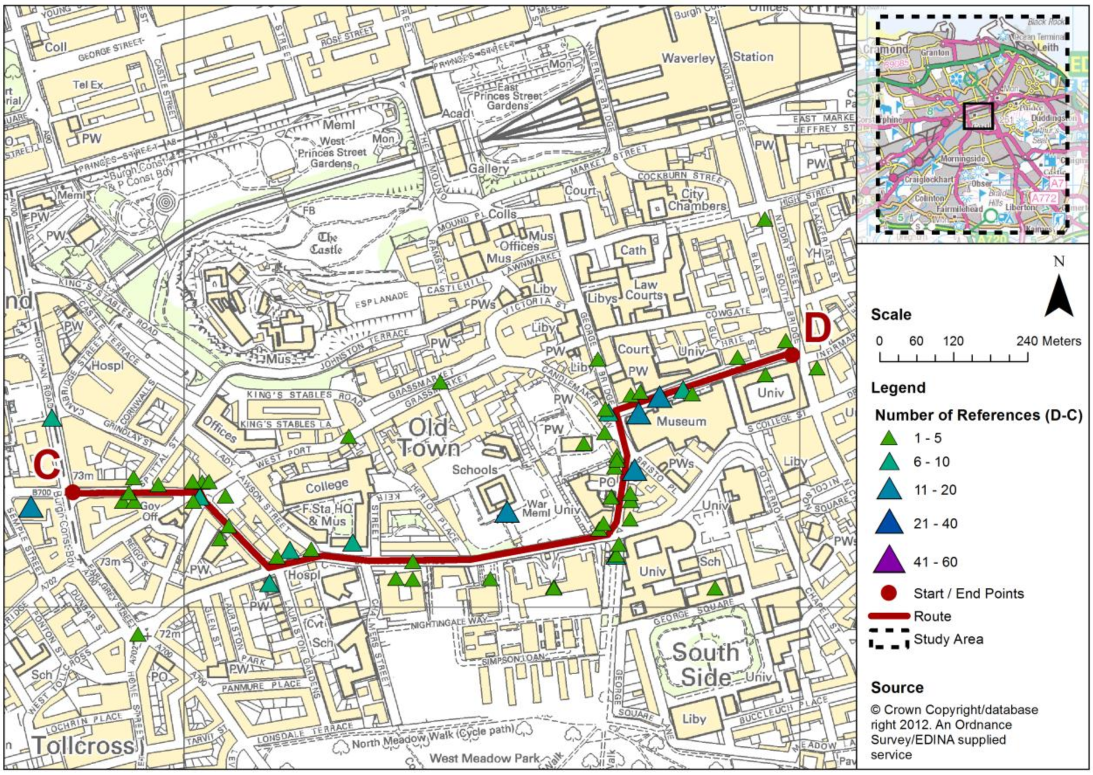


Figure 5.14: Map illustrating the location and number of references to the features of interest that were identified by participants in Experiment Three for Route D-C

The findings for *Experiment Three* reinforce the ideas gathered from the previous experiments; the way in which a route is traversed will affect the features that are most salient. Therefore, the degree of visibility of features plays a key role in the generation of route directions.

5.2.2 Vocabulary of Descriptions

The vocabulary used to describe the features of interest was analysed using the same method as *Experiment One*. It was found that all the descriptors used in the short set of directions related to nine of the saliency categories identified in *Experiment One* (Table 5.14). The most frequently used category (apart from name) was size followed by colour and shape.

Saliency Measure	**Percent of References**	**Example Descriptors**
Name	33.6	National Museum of Scotland Royal Mile
Size	11.7	Big, Large, Huge
Age	9.6	Old, New
Colour	7.5	“Variety of façades colours on Victoria Street” “Edinburgh College of Art is Orange”
Decoration and Signage	5.6	“Jester paraphernalia on the Fringe Shop”
Construction	3.8	“Glass façade of the Point Conference Centre” “The cobbled Royal Mile”
Architecture	3.6	“St Giles is a Gothic Cathedral”
Function	3.6	Theatre, School, Church
Shape	3.5	“Point Restaurant is triangular shaped “Victoria Street curves around”

Table 5:14: Subset of the saliency categories for the features of interest used in Experiment Three

Interestingly, within this experiment there were several descriptors relating directly to road intersections. These included the participants describing the size of the intersections as ‘big’, ‘large’ or ‘huge’ whilst also describing the shape of the intersections as ‘T-junctions’, ‘crossroads’ or ‘the road forks into two’. This illustrates that not only is it important to include junctions as a feature of interest type (as identified by the classification schema in *Experiment Two*) but also illustrates how the saliency categories identified in *Experiment One* can be applied across the different features types regardless of whether the feature was mentioned in the corpus of the first experiment.

All of the forty participants mentioned the gradient of the roads within their directions for Route 1 while only ten participants mentioned gradient for Route 2. This meant that they were referring to either walking up or down a road on the route and, on average, gradient was mentioned three times within a route description. This was occurring on roads such as the Royal Mile, Grassmarket, and Victoria Street (Figure 5.15). The change in gradient was much more pronounced in Route 1, than Route 2. This resulted in the significantly larger number of mentions of gradient within the directions for Route 1. Interesting only two people mentioned the compass direction in their directions, such as “then heading south, we turn right onto Victoria Street” (Participant 36). These compass directions were correctly included within the descriptions. Six people mentioned the distance of a section of the route to be walked, such as “walk for 100 metres, then turn left” (Participant 25). These generally tended to overestimate the distance that had to be walked. It is, therefore, important to include references to gradient in the directions, however, compass directions and distance measures are not so important.

Figure 5.15: The gradient of Victoria Street

5.2.3 Complex versus Simple Routes

The lengths of the summaries for *Experiment Three* varied greatly, with the number of words used ranging from 69 to 847 (Table 5.15). This reflects not only individual styles and memory but, in some cases, also the familiarity with the area, as the two longest descriptions, in each route, were generated by a participant that had lived in Edinburgh for ten years or more and knew the study area extremely well. The average word length of the quick set of directions, however, was approximately 200 words.

	Route 1	Route 1	Route 2	Route 2
Direction	**A-B**	**B-A**	**C-D**	**D-C**
Number of Words				
Min Length	69	71	58	88
Max Length	295	847	339	695
Average	200.0	229.6	181.1	195.0
Number of Individual Propositions				
Min Length	9	9	8	12
Max Length	43	74	44	60
Average	26.9	27.0	25.2	25.3
Features of Interest				
Number	78	84	58	62
No. Of Mentions	310	299	285	260

Table 5.15: Length of the set of route directions generated in Experiment Three

One of the aims of the experiments was to investigate whether or not complex routes generate more detailed route descriptions. From *Experiment Two,* it was found that there was no definitive evidence to support this hypothesis. In *Experiment Three* there are slight differences between the two routes with Route 2 (the simpler route) having marginally shorter length of directions in regards to both the number of words and the number of minimal propositions. Features of interest are also marginally less often mentioned for Route 2 than Route 1 (Table 5.15). The results, therefore, from *Experiment Three* support the findings from *Experiment Two*, that even though there are slight differences these are not significant enough to adequately conclude that there is a discernible difference in the way route directions are developed for simple and complex routes.

5.2.4 Familiarity

Familiarity plays a key role in spatial cognition and numerous studies have shown positive links between familiarity and the accuracy of the cognitive map (Hirtle & Hudson, 1991; Mainardi Peron *et al.*, 1990). Familiarity with an environment has also been shown to reduce wayfinding errors (Brill *et al.*, 1984; O'Neill, 1992). This research, therefore also investigated the links between the participants' familiarity with the study area, and the directions, to see if the participants' familiarity had an effect on the length of the summary and the number of features that were being recalled.

Two variables were calculated to evaluate this. The first was the length of time in months that the participant has been living in Edinburgh and the second was a familiarity variable, the development of which was outlined in Chapter 3. The construction of this variable is discussed in Section 3.3.4. These two variables were tested against the number of words in the full summaries, the number of words in the reduced proposition summaries, the actual number of individual proposition statements, and the number of features identified in the directions (Table 5.16). When it came to the participant's length of residency there was a significant and reasonably strong positive relationship with all three of the length of summary variables of approximately 0.5. The variables, however, show that there is only a weak positive relationship with the familiarity variable (approximately 0.3), although this correlation is significant at the 0.05 level. This means that whilst the length of time a person has been resident in the area slightly affects the route information they remember, and in turn the length of the summaries, their familiarity with the study area has a much lesser effect.

Overall	**Residency (months)**	**Familiarity**
Full Length (words)	0.496**	0.314**
Proposition Length (words)	0.455**	0.303**
Number of Protocols	0.462**	0.258*
Number of Features	0.483**	0.267*

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 5:16: Correlation of Familiarity against the length of the summaries

5.2.5 Male versus Female Route Directions

As stated in Chapter 2, previous research has found that females refer to visual landmarks more frequently than males (Denis, 1997; Galea & Kimura, 1993; Ward *et al.*, 1986). Ward *et al*. (1986) found females more likely to refer to environmental features when giving route directions whereas males included more references to metric distance and cardinal directions in their descriptions. Females often used landmarks more than males in their directions (Lawton, 2001; Napoleon, 2007), however, others researchers have found that there is no distinct difference between the use of landmarks in directions between the sexes (Ewald, 2010; Harrell *et al.*, 2000) .

Within *Experiment Three*, the overall findings of all route directions generated, regardless of the route travelled, found that females tended to provide more information in their short directions. This is shown through the length of the descriptions both in terms of the average length of the summaries and the standardized set of minimal propositions (Table 5.17). The average number of features referred to within the directions, however, was similar between males and females.

	Males	**Females**
Average Length of Summary (words)	179.1	223.7
Average Length of Proposition (words)	148.4	166.9
Number of Propositions	24.7	27.5
Average Number of Features	13.8	15.0

Table 5.17: Differences between directions lengths for Males and Females

When breaking the length of the summaries down by route, however, it can be seen that females used more information than males when it came to describing the complex route (Route 1), whereas similar amounts of information were used by both males and females when it came to describing the simpler route (Route 2) (Table 5.18).

	Route 1	Route 2
Males		
Average Length of Summary	169.6	188.7
Length of Proposition	133.6	163.4
Number of Propositions	24.0	25.4
Average Number of Features	14.1	13.6
Females		
Length of Summary	260.0	187.5
Length of Proposition	188.2	145.5
Number of Propositions	29.9	25.1
Number of Features	16.4	13.7

Table 5.18: Differences between directions lengths for Males and Females, by Route

When looking at the differences in the features used, the complex route again found females using a larger set of features (87) in their descriptions in relation to males (73). This resulted in the features being mentioned more frequently in the females (327) directions as opposed to males (282). The features, however, had a very strong overlap with 55 features being commonly used between males and females. These 55 features accounted for the majority of features mentioned within the directions (86 percent of the features mentioned for males and 89 percent for females).

In relation to the simpler route, there was a slight difference between the features used in the directions, with females identifying an additional ten features (69 compared to 59). There were 54 common features between the male and female directions and these features accounted for 95 percent and 88 percent respectively of the features mentioned within the directions.

Additionally, there were no distinct differences between the types of features of interest that were used within the descriptions. Both males and females used references to the predominant categories of features that were identified in the previous two experiments; buildings (single or part), streets, and statues and monuments.

In conclusion, whilst females may include more information in their route directions for more complicated routes, there is no significant difference in the type of features mentioned and how often they are mentioned between females and males, thus agreeing with the findings of Ewald (2010) and Harrell *et al.* (2000). It can, therefore, be concluded that when developing an automated route navigation system there is no requirement for developing different sets of directions based on whether the user is male or female.

5.2.6 Modelling Summary

The findings from *Experiment Three* are important as they reinforce the findings in the previous studies. Firstly, it identified that buildings, streets, and statues and monuments are the key features of interest that occurred most often in the descriptions that the participants produced from memory. These are therefore the features that need to be focussed on when developing the saliency measures. In addition, the large number of features of interest could be reduced down to a minimal set for each direction of each route. This showed that the direction of walking a route matters greatly. Different features are salient when approaching the same reorientation point from different directions. This was a finding that was also identified in *Experiment Two*. Therefore, the pedestrian navigation system requires that the visibility of a feature of interest must be taken into account.

Another finding from *Experiment Three* is the importance of using references to the gradient of the road within the directions, such as “turn left and walk up Victoria Street”. A large number of the directions were clarified with gradient, therefore, in the final route directions generated from the pedestrian navigation system, this needs to be reflected. Interestingly, references to both compass direction and distance were extremely limited, illustrating that these are not important within a more natural way of direction giving.

Finally, when investigating the vocabulary used to describe the features identified, it was found that all the descriptors fitted into a subset of nine of the saliency categories identified from *Experiment One*. Several of the categories that were not mentioned were the more subjective ones of ‘emotions towards feature’ and ‘condition’. Additionally the ‘temporality’ category was also not mentioned. This was interesting as, whilst these were categories that were of importance when identifying salient features within an environment, when it comes to identifying features from memory for use within direction giving they were not mentioned. The pedestrian navigation system, therefore, should focus more on the saliency variables that can be measured and are not liable to change.

5.3 Summary

Referring back to the five aims identified at in Chapter 3 for these experiments, it can be seen that a large variety of features are deemed to be salient in the urban landscape from buildings, statues, and roads to street furniture, greenspaces, and temporary features such as road works and building sites (*Experiment Two*). These are deemed salient due to a variety of categories including size, age, colour, condition, shape and location (*Experiment One*). The direction of travel affects the visibility of features, with different features being used to describe the same decision point when travelling in opposite directions meaning that visibility must be taken into account when selecting the most salient feature of interest to use at a reorientation point (*Experiment Two* and *Three*). A participant’s length of residency in the area slightly affects the route information they recall which, in turn affects the length of their direction summaries. Their familiarity with the study area, however, has a much lesser effect that length of residency (*Experiment Three*). Finally there were no distinguishable differences between the simple and complex route directions or those directions generated by male or female participants (*Experiment Two* and *Three*).

The three landmark experiments provide the empirical evidence to support the modelling requirements in an automated route direction system, and they help identify the criterion that governs the saliency of features of interest in the urban environment. It is essential to note that there are a number of ways that the saliency of a feature can be measured, however, the most important facet of the saliency of a feature of interest is the fact that it must stand out from the surrounding area. It is therefore essential to develop a method that allows the selection of the most salient feature for use at each possible decision point. This method must take into account the visibility from the decision point, which will be different depending on the direction of travel. The following chapter will discuss the implementation and development of the pedestrian navigation system based on the findings from these three experiments.

Chapter 6

Technology and Data Specifications and Descriptions

Chapters 4 and 5 presented the results of three experiments which detailed the requirements for pedestrian navigation system, including the saliency categories to be measured for the different feature types, the importance of visibility, and the information required in the final route directions. Before discussing how these requirements were implemented, it is necessary to introduce the technological and data foundations for the system. This chapter presents an overview of the technology employed in the development of the web-based pedestrian navigation system (Section 6.1) and the various datasets that are used to identify and extract the features of interest and their associated saliency (Section 6.2). The datasets used to provide a routing network are also introduced and discussed.

6.1 Technology

The technological requirements for the system were two-fold. First, there needed to be software that supported the automatic identification of the features of interest and the creation of the variables to measure their related saliency. Second, although the functional specification of the pedestrian navigation system could nowadays be applied to mobile devices, the system was designed to provide a desktop web-based interface in which a start and end point could be specified and a route returned and displayed on a map. It was determined that the best way to display this interface would be via a webpage, therefore, software was required that supported the display of spatial data over the web and had the ability to perform routing analysis in real time.

The functional requirements of the pedestrian navigation system were:

- The ability to store, access, and process large datasets
- The ability to serve data to the web
- The ability for a user to interact with the mapping
- The ability to efficiently perform shortest path routing
- The ability to develop own functions to automate the development of saliency variables

A number of methods were considered for the development of the pedestrian navigation system. As the system was intended to be web-based and as flexible and extensible as possible, the use of ESRI ArcGIS software to develop the entire system was deemed unsatisfactory unless no feasible alternative could be found, due to the proprietary nature and relatively high cost of ESRI software. Due to the large volumes of spatial data required for the development of all aspects of the pedestrian navigation system, it was decided that a spatial relational database would be the most efficient method of storing, retrieving, viewing, and analysing the data. This again ruled out the use of ArcGIS connected to a spatial database as an ArcSDE license would be required. ArcGIS also would not be suitably flexible for the task required. It was, however, determined that ArcGIS would be required for the development of the variables measuring saliency, as it was deemed to provide the best way of handling and processing the raster datasets.

When looking at the software for spatial databases, three different database management systems were considered; Oracle Spatial, PostgreSQL/PostGIS, and MySQL. At the time of deciding on the technology to be used, MySQL had only basic spatial functions available and no routing analysis. Oracle Spatial and PostgreSQL/PostGIS both had a large variety of spatial functions and operations and both could be extended to provide routing functionality. PostgreSQL/PostGIS was the spatial database chosen due to the ease of the setup of the routing functionality and its ability to interact with a large number of other technologies that could provide the web mapping capabilities (Figure 6.1). PostgreSQL and PostGIS provide the database backend to the web based system, whilst also supporting the development of functions to help create the variables measuring a feature's saliency. The web mapping server chosen was MapServer as it is well established and primarily focussed on WMS services. OpenLayers was utilised to enrich the display of the spatial map that was presented by MapServer. The desktop GIS applications of ArcGIS and Quantum GIS (QGIS) were used to support the development of the saliency variables that interacted with raster datasets, such as the LiDAR data. This was due to there being no raster support within PostgreSQL/PostGIS at the time of development.

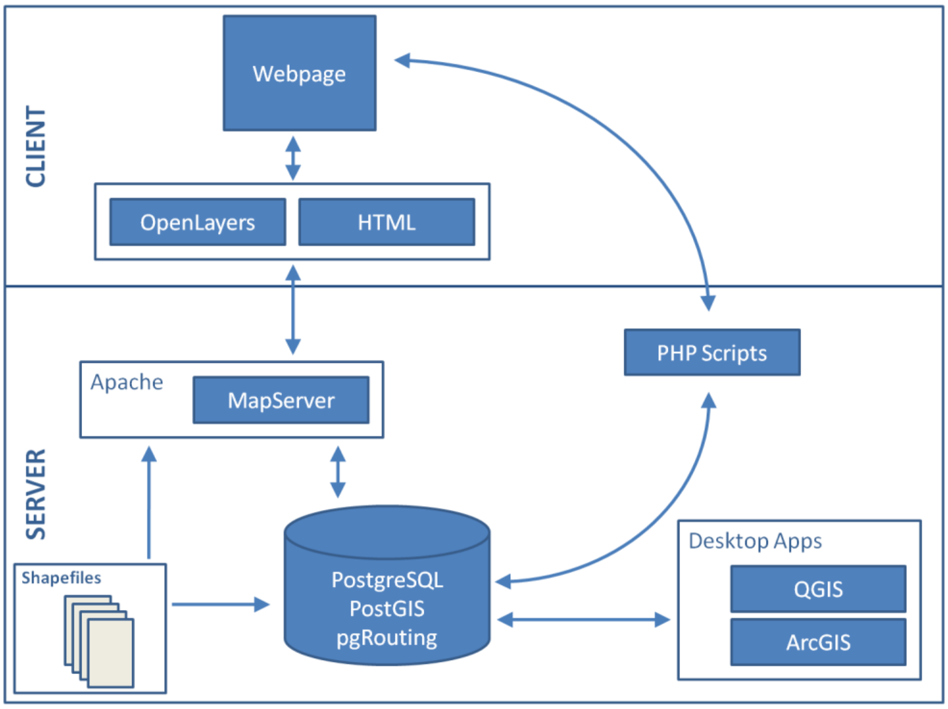


Figure 6.1: The technology used within the development of the pedestrian navigation system and their interactions with each other

The web-based pedestrian navigation system was built using a variety of free and open source technology; including PostgreSQL, PostGIS, MapServer, and OpenLayers. One of the major advantages for the use of open source software is that there are standards in place, specified by the Open Geospatial Consortium (OGC) that ensures interoperability between the different pieces of software. This means that a large variety of software can be used together without being limited to one vendor. Other advantages include the fact that open source software is generally undergoing consistent development focussing on both enhancements and bug fixing, thus ensuring that issues that arise within the software are dealt with quickly. There is an active developer and user network which can provide help in an extremely timely manner. Additionally there is the benefit of reduced costs associated with open source software. The use of open source software also means that a user is not confined to one set of solutions. Rather they are able to 'pick and choose' from a variety of software that perform similar functions. For example, if a user required a web mapping service (WMS) they could choose from MapServer, GeoServer, Deegree, Geomajas, or MapGuide or if they required an open source desktop solution then their options would include Quantum GIS, gvSIG, uDig, OSSIM, or Grass GIS.

6.1.1 PostgreSQL & PostGIS

PostgreSQL is an object-relational database system that has been under continual development for the last 15 years (The PostgreSQL Global Development Group, 2012). It is currently one of the world's most popular database management systems and is often referred to as the most advanced open source database in existence and has been claimed to have the functionally to compete with commercial databases, such as Oracle (Oracle, 2012).

PostGIS 'spatially enables' PostgreSQL. It provides numerous spatial data types (such as the point, lines, and polygons) and extends PostgreSQL with over 300 spatial functions. The spatial functions available within PostGIS include the creation of buffers, calculating area and length of features, performing distance calculations, and returning the intersections and unions of features (Obe & Hsu, 2011). PostgreSQL and PostGIS are both used by a number of major mapping agencies including the Institut Geographique National (IGN France), InfoTerra (United Kingdom) and Edina (United Kingdom) (Ramsay, 2007).

An advantage of using PostGIS is that it implements the Open Geospatial Consortium 'Simple Features Specification for SQL' and has been certified as compliant by the OGC with the 'Types and Functions' standards. This means that datasets within PostGIS (and query results) can be displayed by other open source technologies such as QGIS and MapServer.

Additionally within PostgreSQL/PostGIS there is the ability to write customised spatial functions using PL/pgSQL, a procedural language for the PostgreSQL database system. This procedural language was used within the thesis to generate the methods for developing the saliency variables, such as automatically associating the name to the features of interest from various datasets, determining the façade length of a building, attributing the cultural and historical variables to a feature, and generating the location based saliency variables; such as its location in relation to a road, a decision point, and to other buildings. The version of PostgreSQL 8.4 was used for the development of the pedestrian navigation system, together with PostGIS 1.5.1.

6.1.2 pgRouting

PgRouting is an extension developed for PostgreSQL/PostGIS that allows for routing functionality to be performed (PgRouting, 2012). Its foundations were in the SQL module pgDijkstra developed by Camptocamp to perform the Dijkstra Shortest Path Algorithm (CartoWeb, 2012). In 2006, pgDijkstra was extended by Ornkey (Japan) and become pgRouting which included a wider range of routing functionality. This functionality includes three different shortest path calculations (Dijkstra, A*, and Shooting Star), driving distances and isochrones, and a method to solve the travelling salesman problem (a geographical resource allocation problem) (PgRouting, 2012). Within this thesis, Dijkstra was chosen as the shortest path algorithm that would be used as it was able to be implemented robustly compared to the other available algorithms.

The advantages of using a database routing solution are that it can interact with a number of different applications, the data changes are reflected immediately in the results, and cost values can be calculated using SQL queries (PgRouting, 2012). Additionally, pgRouting provides the ability to serve the route results out to a number of different desktop and web applications. Using a database to solve routing problems is an extremely efficient method of providing and displaying the results in a timely manner to a web-based system.

6.1.3 MapServer

MapServer is a project of the Open Source Geospatial Foundation (OSGeo). MapServer is a development environment for building spatially-enabled web mapping applications and services. MapServer is able to render map images for delivery to a client on-the-fly and display dynamic maps over the internet. It supports the display and querying of a large variety of raster, vector, and database formats. MapServer incorporates a number of the OGC standards on both web map services (WMS) and web feature services (WFS) which allows it to interact with other open source technologies, including Quantum GIS which has functionality to automatically create the map files required by MapServer (MapServer, 2012).

Finally, it is designed to support a large number of scripting languages including PHP, Python, and Java (MapServer, 2012). PHP was used for the development of the internet side of the pedestrian navigation system. MapServer 5.2.2 was installed on an Apache web service (Version 2.2.14). Within this thesis, MapServer has been used to serve out a WMS of the raster background mapping to the web interface of the pedestrian navigation system.

6.1.4 OpenLayers

OpenLayers is a web-mapping client-side API, built on a JavaScript library that can be used to build web-based geographic applications. In general, it aids the display of map data on web pages. Its development started in 2005 and was then subsequently released as open source software in 2006 by MetaCarta Labs. OpenLayers is currently the most popular web-mapping client, primarily due to its ability to allow both OGC-complaint and non-OGC-complaint WMS and WFS layers to be used and overlaid in a single map (Obe & Hsu, 2011).

OpenLayers greatly enriches the viewing experience for the user, for example it can adds the zoom and pan buttons to the map, allows the user to turn on and off layers, allows the user to add a number of different layers from tile images (WMS, Google Maps, OpenStreetMap) to vector features (WFS, KML, GeoJSON, WKT, GML). It can also be used for web-editing of spatial data.

Within the pedestrian navigation system OpenLayers 2.9.1 has been used to provide the display functionality for the map, including allowing the user to interact with the map to provide the start and end point for the route required. OpenLayers also provides the functionality to display the resultant route on the map, as a vector layer, from the GeoJSON format that is retrieved from the PostgreSQL/PostGIS database.

6.1.5 Desktop GIS (Quantum GIS & ArcGIS)

Functionality within both Quantum GIS (QGIS) and ArcGIS were both used to aid the development of the variables measuring a feature’s saliency. They have primarily been used for the interpretation and analysis of the LiDAR data (discussed in Section 5.2.5). This analysis included calculating the height and visibility of features of interest. Desktop GIS software was used as PostGIS did not have the functionality to load, store, and analyse raster data (PostGIS, 2012).

6.2 Datasets

As identified and discussed in previous chapters, the study area is the City of Edinburgh. A number of datasets were gathered together from a variety of sources, including Ordnance Survey, Historic Scotland, Cities Revealed, and the Gazetteer for Scotland, for use within the pedestrian navigation system to model the factors identified as key to pedestrian navigation in Chapters 4 and 5. In Chapters 4 and 5, the key saliency measures and features of interest that need to be modelled were identified. Within this chapter we identify datasets required to fulfil these requirements. Table 6.1 presents a mapping between the identified saliency measures from Chapter 4 and the datasets that can be used to represent the variables to measure saliency in Chapter 7. Several of the saliency categories have been left blank, such as conditions and colour, as there is currently no available datasets that could be accessed to automatically calculated saliency variables.

The primary datasets used come from the Ordnance Survey MasterMap product. This product provides the Integrated Transport Network (ITN) which provides the basis for the web-based routing. MasterMap also provides a Topography layer from which the features of interest are identified and many of the saliency variables calculated. Other datasets are used to calculate additional variables to measure a feature’s saliency. Each of the datasets are introduced below.

Saliency Measure	Dataset Used to Generate Variables
Name	OS MasterMap - Topography Layer OS MasterMap - ITN Roads and Paths PointX - National Points of Interest Gazetteer for Scotland RCHAMS - Canmore Database
Size	OS MasterMap - Topography Layer OS MasterMap - ITN Roads and Paths Cities Revealed - LiDAR Data
Age	RCHAMS - Canmore Database Cities Revealed - Building Class Gazetteer for Scotland
Colour	
Emotions towards Features	
Decoration and Signage	PointX - National Points of Interest
Location	OS MasterMap - Topography Layer OS MasterMap - ITN Roads and Paths
Construction	Gazetteer for Scotland RCHAMS - Canmore Database
Architecture	Historic Scotland - Listed Buildings
Function	PointX - National Points of Interest Cities Revealed - Building Class
Shape	OS MasterMap - Topography Layer OS MasterMap - ITN Roads and Paths
Condition	
Cultural & Historical	Historic Scotland - Listed Buildings Historic Scotland – World Heritage Sites Historic Scotland – Scheduled Monuments PointX - National Points of Interest Gazetteer for Scotland
Temporality	

Table 6.1: The datasets used to generate the variables measuring saliency

6.2.1 Ordnance Survey MasterMap

Ordnance Survey's (OS) MasterMap is a topographic dataset that provides complete coverage of Great Britain. MasterMap is comprised of features which represent real-world objects, such as buildings, roads, rivers, structures, and land parcels and it is continually updated through ground and aerial surveys (Ordnance Survey, 2012f). The classification of the real-world objects is detailed in OS MasterMap Real-World Object Catalogue (Ordnance Survey, 2012e).

MasterMap comprises four separate layers; Address Layer 2, Imagery Layer, Integrated Transport Network (ITN) Layer, and the Topography Layer. These layers have over 450 million features representing real-world features across the four products. Address Layer 2 contains approximately 29 million addresses which can be linked to the other datasets via a unique identifier (Ordnance Survey, 2012a). The Imagery Layer is a set of aerial images, with a resolution of 25cm. These images have been orthorectified allowing the features in the image to align across the other products (Ordnance Survey, 2012b). All layers, apart from Imagery Layer, are provided in a compressed GML format. Software such as Dotted Eyes's SuperpOSe, ESRI's Productivity Suite (a plug-in for ArcGIS) or Snowflake's GOloader can be used to load the GML files into spatial databases. Productivity Suite was used to convert the data.

6.2.2 OS MasterMap Topography Layer

The Topography Layer was the first OS MasterMap layer to be produced in November 2001. It is a vector-based layer representing features that appear in the landscape, such as buildings, roads, and water, but also includes administrative boundaries. It contains over 425 million individual features, thus providing a very detailed view of the landscape of England, Wales, and Scotland (Ordnance Survey, 2012f). Within the study area there are 1.2 million individual features provided. There are nine different themes within the Topography Layer; Administrative Boundaries, Buildings, Heritage and Antiquities, Land, Rail, Roads, Paths and Tracks, Structures, Terrain and Height, and Water (Figure 6.2). The features within these themes are collected to a very high level of detail; urban areas are captured at a scale of 1:1250, rural areas at 1:2500, and mountains and moorland at a scale of 1:10,000. Each feature is represented by a point, line, or polygon and has rich set of attribution associated to it, including referencing and life cycle attributes, and feature descriptions such as descriptive group and descriptive term (Ordnance Survey, 2012f).

Figure 6.2: Extract of OS Master Map Topography Layer

This primary dataset forms the basis of the pedestrian navigation system and is used for the identification of the features of interest and is used in several of the calculation of the related variables measuring saliency, such as size, shape, and location.

6.2.3 OS MasterMap: ITN Roads and ITN Urban Paths

The ITN Road Layer contains information about the road network and its associated road routing information (such as use and speed restrictions). The Road Layer currently has approximately 13 million road features and 1.5 million items of road routing information (Ordnance Survey, 2012c). Within the study area there are 14,158 road and 7,934 path features.

ITN Urban Paths is the newest addition to the MasterMap datasets, released in 2010. It has been designed to extend the capabilities of the ITN Road Network by allowing for a more complete multi-modal transport model. The Urban Path Network includes footpaths, subways, steps, footbridges, and cycle paths in all urban areas over 5km^2 in Britain. Path routing information includes path names and environmental qualifiers classifications such as footbridge, steps, or subway (Ordnance Survey, 2012d).

ITN Road and Urban Paths Networks are logical networks consisting of road or path centrelines in a link and node structure. Urban Paths extends the functionality of ITN Road Network by adding additional lines and nodes to join the paths to roads resulting in a full network which allows routing over both layers (Figure 6.3).

Figure 6.3: Extract of OS Master Map ITN Road and Urban Path Network Layers

Within this thesis, the ITN Road and Urban Paths Networks were combined to provide a detailed routing network for the City of Edinburgh. The aim of this research was to provided natural route descriptions for the pedestrian, therefore it was necessary to ensure the routing network was appropriate for pedestrian walking. The ITN Network is provided with additional routing information, such as environmental, vehicle, and day and time qualifiers. This information provided the name of the roads and paths as well as additional classifications (such as steps, cycle path, and footbridge) for the paths.

6.2.4 PointX: National Points of Interest

PointX was formed in 2001 as a joint venture between Ordnance Survey and Landmark Information Group in order to create a point of interest dataset. The resulting National Points of Interest database has over four million points which are continuously maintained. Within the study area there is approximately 23,000 points of interest. It has been compiled from a large number of different suppliers including (but not limited to) Ordnance Survey, Royal Mail, UK Payphones, and Visit Britain (PointX, 2012b).

The point of interest data has a three tier classification schema. Within the first level there are 9 classifications groups (Table 6.2) whereas level two has 52 categories and level three has 620 classes (PointX, 2012a). The points of interest are shown in Figure 6.4. Every point can be related back to the OS MasterMap Topography Polygon and ITN Layers through the use of a unique identifier (TOID). This links the point of interest to the polygon feature it lies in and the road that it is are located on within MasterMap.

ID	Top Level Classification
01	Accommodation, Eating and Drinking
02	Commercial Services
03	Attractions
04	Sport and Entertainment
05	Education and Health
06	Public Infrastructure
07	Manufacturing and Production
08	Retail
09	Transport

Table 6.2: PointX's Level 1 Classification Groups (PointX, 2012a)

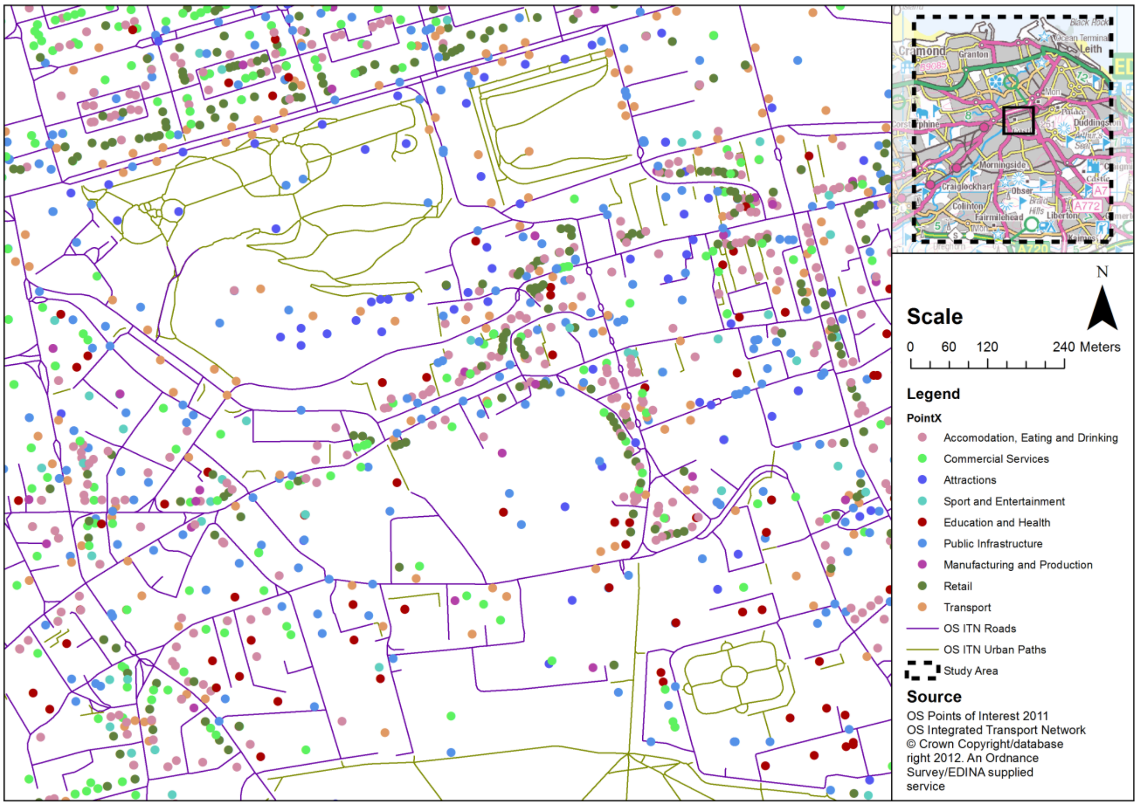


Figure 6.4: Extract of PointX's National Points of Interest (shown by level 1 classification)

PointX is used within this research to provide not only names for features, especially regarding the occupants of buildings, but also to provide information for the function and signage of the feature, and to help identify the historical and cultural importance of a feature. The application of PointX to the various saliency categories is discussed within Chapter 7.

6.2.5 Cities Revealed: LiDAR Data

Cities Revealed has made LiDAR (Light Detection and Ranging) data available for the entire City of Edinburgh at 2m resolution through the Landmap Spatial Discovery Portal (Landmap, 2011a). This data was collected in 2006 by Infoterra Airborne and each height point has a vertical accuracy of +/- 15 cm. The data are supplied pre-processed as both a Digital Terrain Model (DTM) and a Digital Surface Model (DSM). The DTM represents the ground surface only (Figure 6.5) whilst the DSM represents the ground and all features on it, such as buildings and vegetation (Figure 6.6).

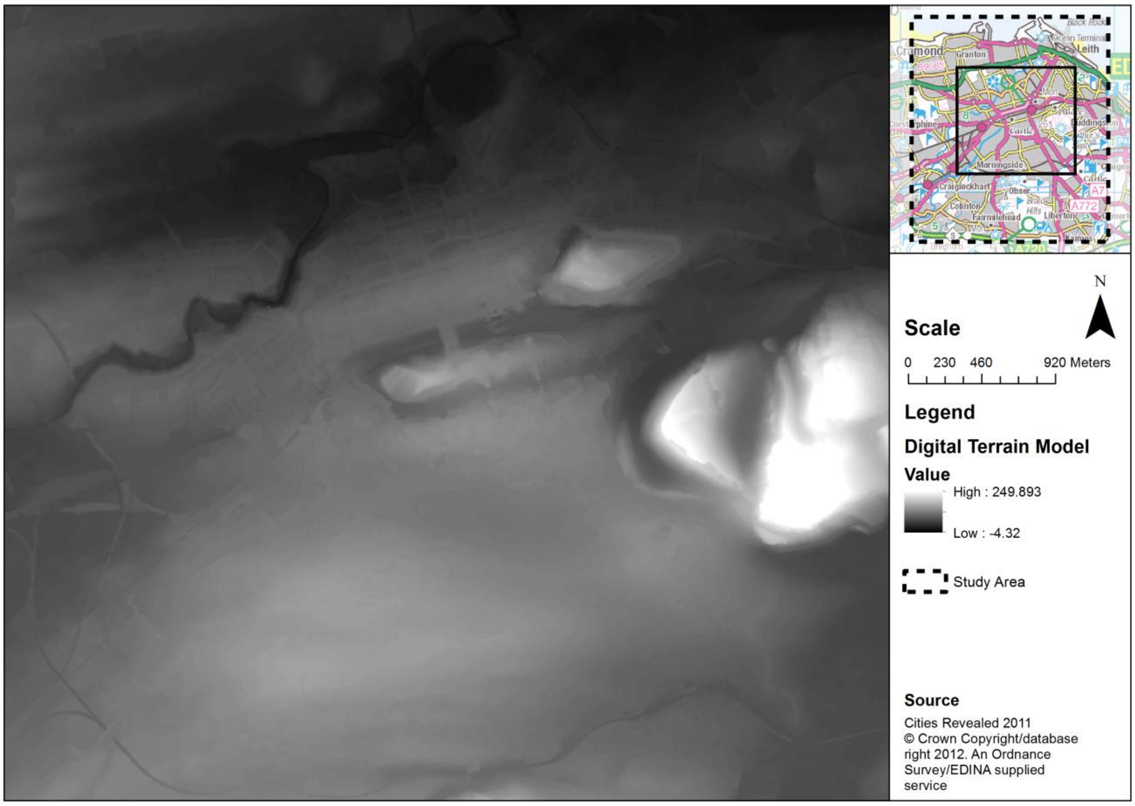


Figure 6.5: Extract of LiDAR data DTM for the City of Edinburgh

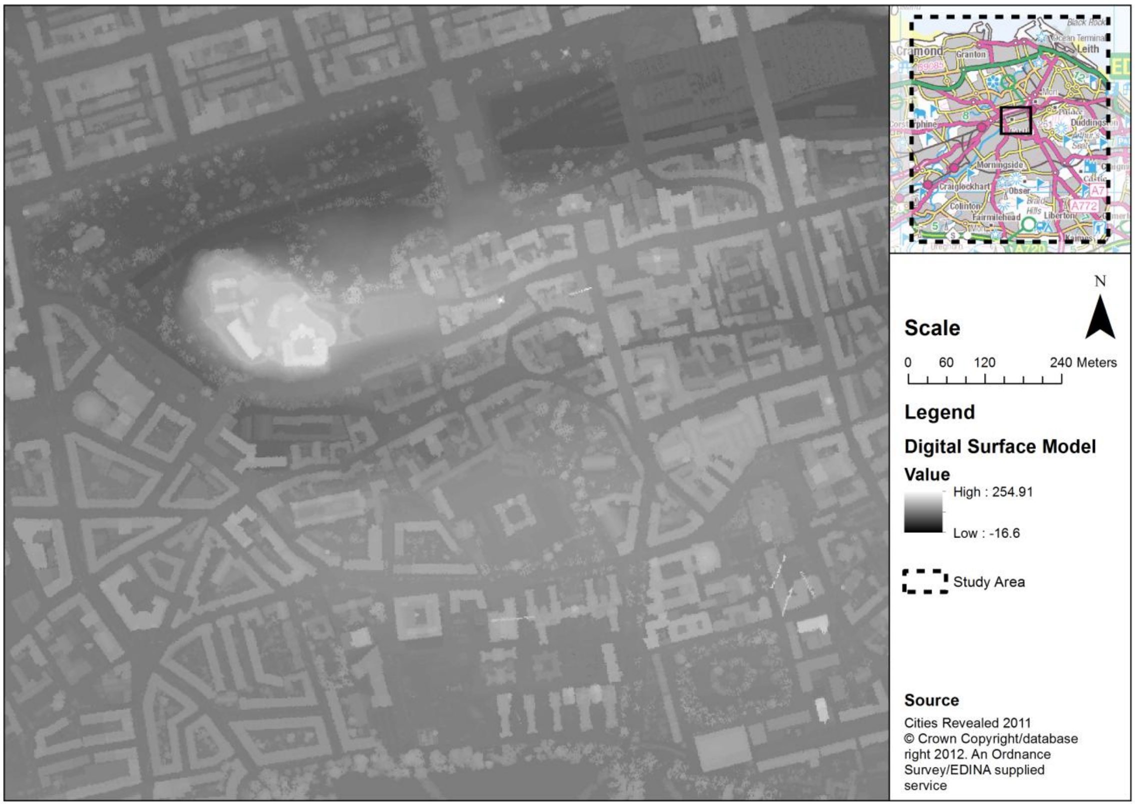


Figure 6.6: Extract of LiDAR data DSM for the City of Edinburgh

The LiDAR data provides information for the calculation of height and volume variables for the size saliency category (discussed in Chapter 8). It also provides the model for the visibility analysis for the features of interests (discussed in the Chapter 7).

6.2.6 Historic Scotland: Listed Buildings, World Heritage Sites, and Scheduled Monuments

Historic Scotland is an agency of the Scottish Government charged with protecting Scotland's historic environment (Historic Scotland, 2012c). As part of this task they determine the buildings that should be listed in order to protect them for the future. For a building to be listed in Scotland it must be of 'special' interest. This interest may fall in to one or more of the following three areas; age and rarity, architectural or historic interest, or close historical association. The term building is broadly defined and refers to buildings as well as features such as walls, fountains, statues, or bridges (Historic Scotland, 2012a). Each listed building is assigned to one of three categories according to their importance (Table 6.3, Figure 6.7). Within the study area there are approximately 9,000 listed buildings. The listed building dataset has been used to help determine the architectural and historical significance of features.

Category	**Explanation**
A	Buildings of national or international importance, either architectural or historic, or fine little-altered examples of some particular period, style or building type. (Approximately 8% of the total).
B	Buildings of regional or more than local importance, or major examples of some particular period, style or building type which may have been altered. (Approximately 51% of the total).
C(S)	Buildings of local importance, lesser examples of any period, style, or building type, as originally constructed or moderately altered; and simple traditional buildings which group well with others in categories A and B. (Approximately 41% of the total)

Table 6.3: Explanation of the Historic Scotland's categories for listed buildings (Historic Scotland, 2012b)

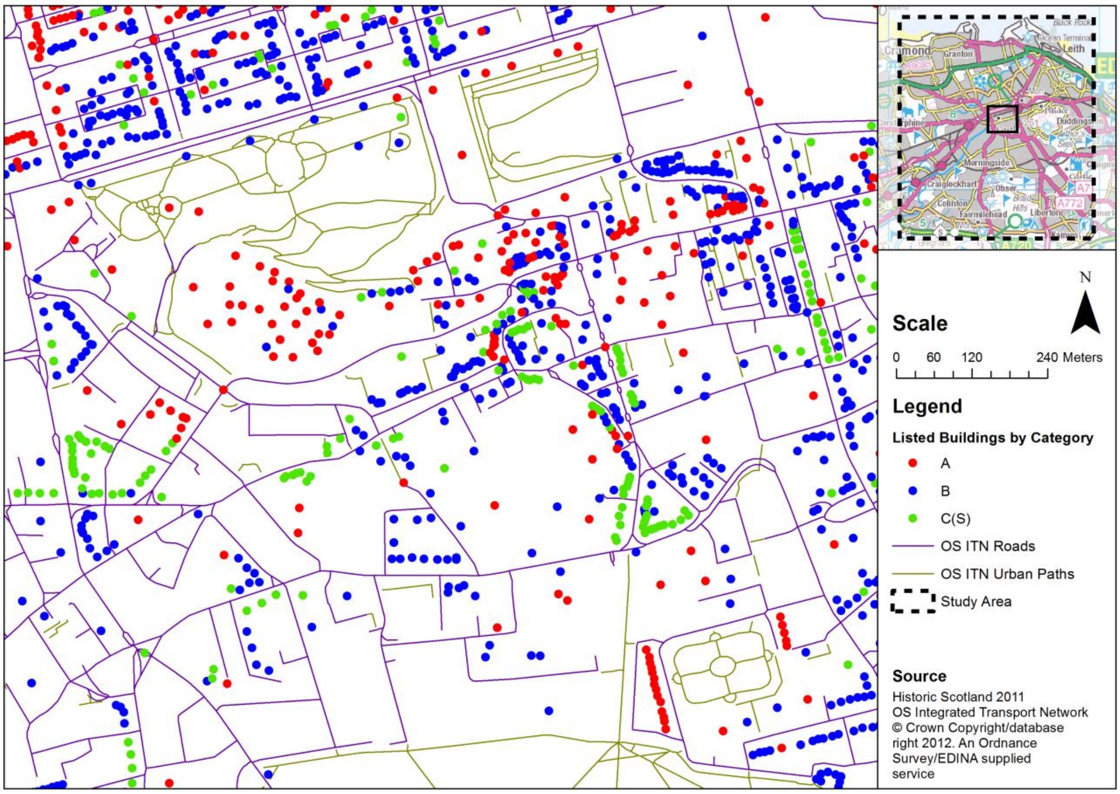


Figure 6.7: Extract of Historic Scotland's Listed Buildings (shown by category)

Within the study area is the World Heritage Site of the Old and New Town of Edinburgh. These areas of Edinburgh were granted as cultural world heritage sites in 1995 in recognition of the "harmonious juxtaposition of the two contrasting historic areas, each with many important buildings" (United Nations Educational Scientific and Cultural Organisation (UNESCO), 2012). The boundary of this world heritage site has been used as a measure of cultural and historical saliency.

Scheduled Monuments are monuments that have been deemed to be of national importance and are viewed to be part of both a local and national identity. They are monuments that contribute to the history, tourism, placemaking, and local distinctiveness of Scotland (Historic Scotland, 2012d). Scheduled Monuments were used as a measure of cultural and historical saliency, following the findings outlined in Chapter 4 and 5.

These three datasets were accessed through the Historic Scotland Data Services which provides access to their repository of GIS datasets (Historic Scotland, 2011).

6.2.7 Gazetteer for Scotland

The Gazetteer for Scotland is a database constituting a geographical encyclopaedia of Scotland, whilst also containing information on its history and people. The Gazetteer maintains information on a wide variety of features including settlements (towns and district), water-related features, land features (such as mountains and valleys), cultural features, transport infrastructure, monuments, tourist attractions, industries, and historical sites (Figure 6.8) (Gazetteer for Scotland, 2012).

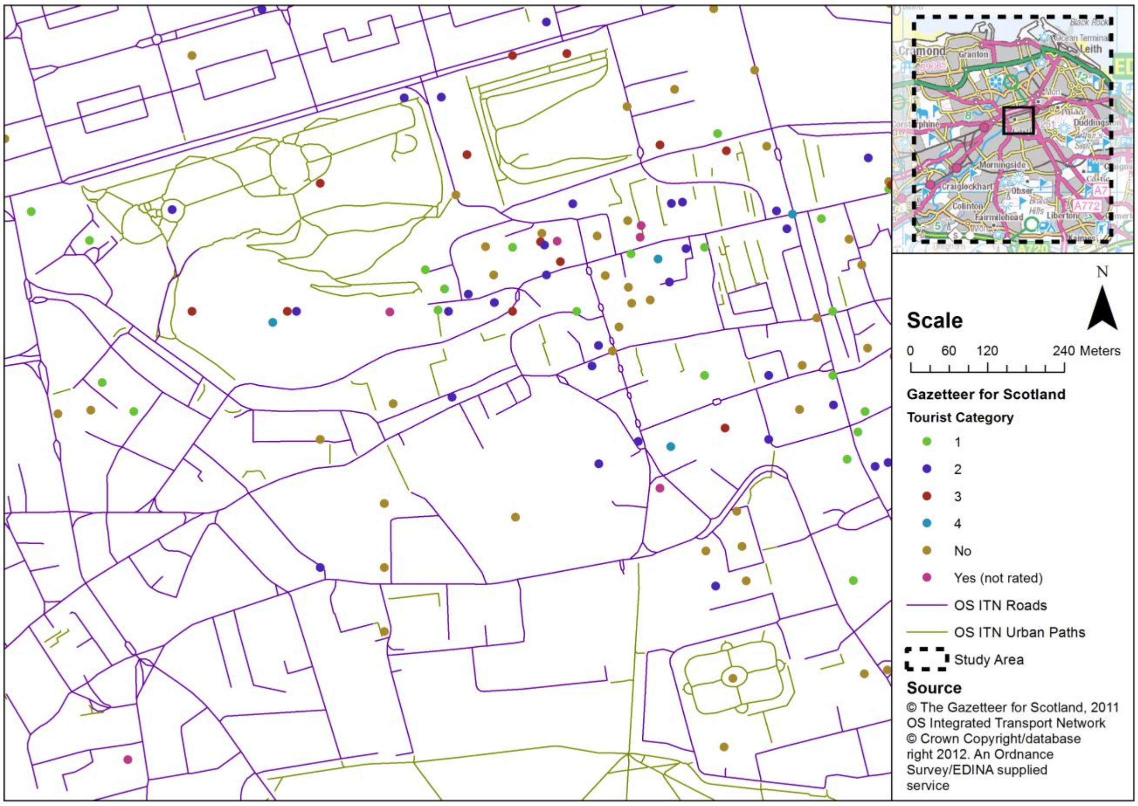


Figure 6.8: Extract of the Gazetteer for Scotland's feature (shown by tourist category)

The Gazetteer has been in development by Bruce Gittings of the University of Edinburgh and the Royal Scottish Geographical Society since 1995 and currently has 20,557 detailed entries and 78,000 short form entries. It is a very unique and valuable dataset to Scotland (Gazetteer for Scotland, 2012).

A full set of the data for the City of Edinburgh (437 features) has been kindly provided by the Gazetteer for Scotland for use within this thesis. This data includes the name and location of the features, it classifications (including sub-types), its tourist attraction classification, and the written text associated with the feature. This data was used within the pedestrian navigation system to determine both the historical and cultural significance of features of interest, and their name. It was also determined that the interpretation of the textual entries within the Gazetteer could help to determine other variables of saliency including age, colour, architecture and construction. The Gazetteer for Scotland is a unique dataset for Scotland and hence does not exist for other countries. If a more general method is needed, similar information could included by data mining sites such as Wikipedia to extract the information required to generate saliency variables such as age, condition, or construction material. This will, however, rely on the richness and completeness of the entries. There are also large technical challenges related to the scraping of such websites. Data mining to extract some the information that is required, such as colour or age, would require intelligence and semantics to be built into such a system to allow it to determine that when, for example a date or year is mentioned, that this applies to the age of the feature rather than to the date of an important event that may of taken place in or around the feature.

6.2.8 Cities Revealed: Building Class

Cities Revealed (now part of The GeoInformation Group) have a unique vector building datasets available detailing Building Classes. This data was available for academic use through the Landmap Spatial Discovery Portal (Landmap, 2011b). The Building Class data provides detailed age and structural data for residential housing. Each building is classified to one of seven age bands (Table 6.4) and one of 17 structural types (Table 6.5). These two classifications are then combined to provide an overall classification for building class. The Building Class is captured from Cities Revealed Modern aerial imager and then verified by ground survey (Cities Revealed, 2010).

Class	Age Description
1	Historic to end Georgian - 1837
2	Early and Middle Victorian 1837 - 1870
3	Late Victorian/Edwardian 1870 - 1914
4	World War I - World War II 1914 - 1945
5	Post war regeneration 1945 - 1964
6	Sixties/seventies 1964 - 1979
7	Recent years 1979 - photo date

Table 6.4: Building Class's age classifications (Cities Revealed, 2010)

Class	Structural Description
1	Very Tall Flats (point blocks)
2	Tall flats 6 - 15 storeys (slabs)
3	Medium height flats 5 - 6 storeys
4	Lower 3 - 4 storey and smaller flats, detached and linked
5	Tall terraces 3 - 4 storeys
6	Low terraces, 2 storeys with large T-rear extension
7	Low terraces, small
8	Linked and step linked houses, 2 - 3 or mixed 2 and 3 storeys
9	Planned balanced-mixed estates
10	Standard size semis
11	Semi type house in multiples of 4,6,8 etc
12	Large property semis
13	Smaller detached houses
14	Large detached houses
15	Very large detached houses, sometimes now flats
16	Bungalows, both detached and semi detached
17	Single storey small houses

Table 6.5: Building Class's structural classifications (Cities Revealed, 2010)

The Building Class is used to create the age saliency category variables within the pedestrian navigation system. However, as the data only covers residential buildings, a large part of central Edinburgh (the commercial areas) still requires the age variable to be calculated from other sources.

6.2.9 Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS): Canmore Database

RCAHMS is an executive non-departmental body of the Scottish Government, financed by the Scottish Parliament through Historic Scotland. RCAHMS is responsible for identification, survey and interpretation of the built environment of Scotland (Royal Commission on the Ancient and Historical Monuments of Scotland, 2012a). This includes curation of one of Scotland's National Collections and they hold approximately 15 million photographs, maps, drawings and documents of Scotland's historic and built environment. The collection is made widely available to the public through web services (Royal Commission on the Ancient and Historical Monuments of Scotland, 2012c).

RCAHMS maintains a database, *Canmore*, which records the locations of sites, monuments and buildings to which its collection relates. This is made available through the online Canmore database portal (Royal Commission on the Ancient and Historical Monuments of Scotland, 2012b). For the study area there is 14,346 entries in Canmore (Figure 6.9). These entries are used, within Chapter 7, for the identification of statues and monuments within Edinburgh. This dataset provides additional information to the age saliency category. RCAHMS Canmore database has a very detailed classification system with over 1,867 sub categories. This data can be linked to Historic Scotland's Listed Buildings using the unique 'numlink' identifier.

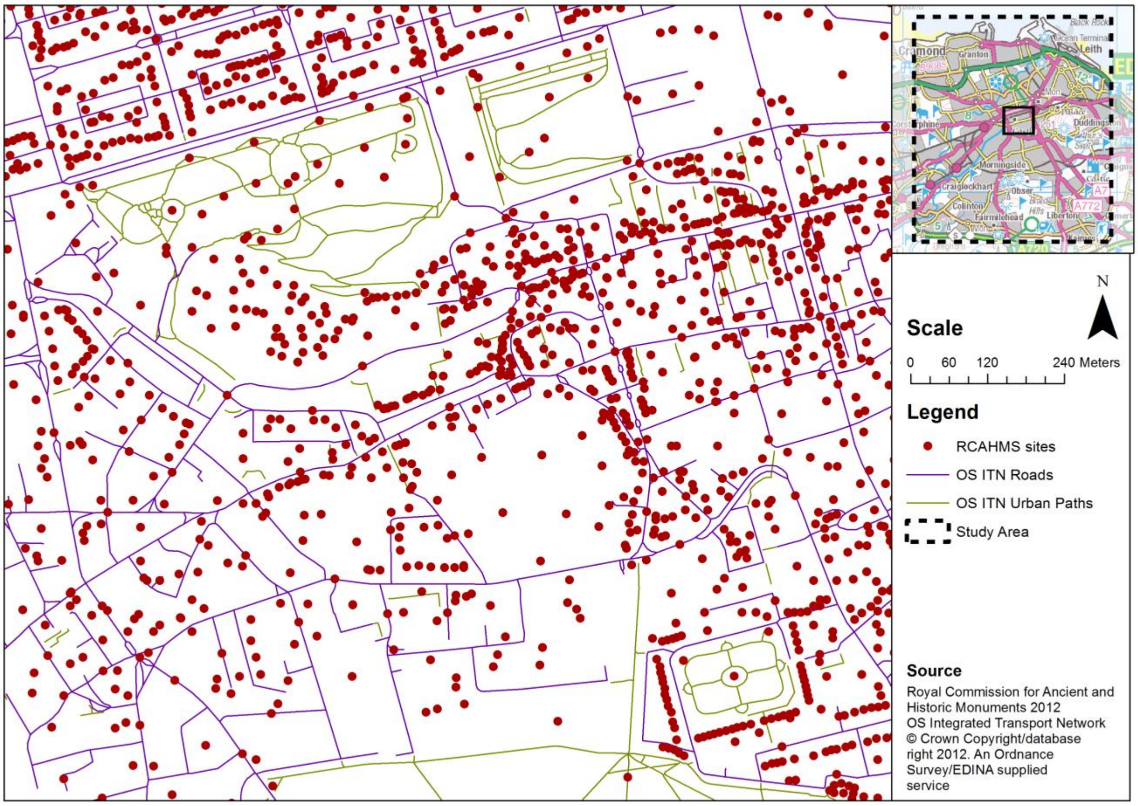


Figure 6.9: Extract of the RCAHMS Canmore database features

6.2.10 OpenStreetMap

OpenStreetMap (OSM) is a collaborative project enabling members of the public to contribute to a freely available and editable map of the world. Mapping provided by OSM is a combination of data created by the public, largely using GPS track logs, spatial data and imagery made freely available by government, including for example Ordnance Survey's Open Data, and copyright free commercial data and imagery (OpenStreetMap, 2012a, 2012b). The availability of data and imagery from government and commercial sources has allowed the OSM to make considerable advances in capturing land-use data (OpenStreetMap, 2012a). OpenStreetMap data will be used to generate names for path features. The use of OpenStreetMap for the identification of the different feature types (identified from the classification schema) will be discussed further within Section 7.1.

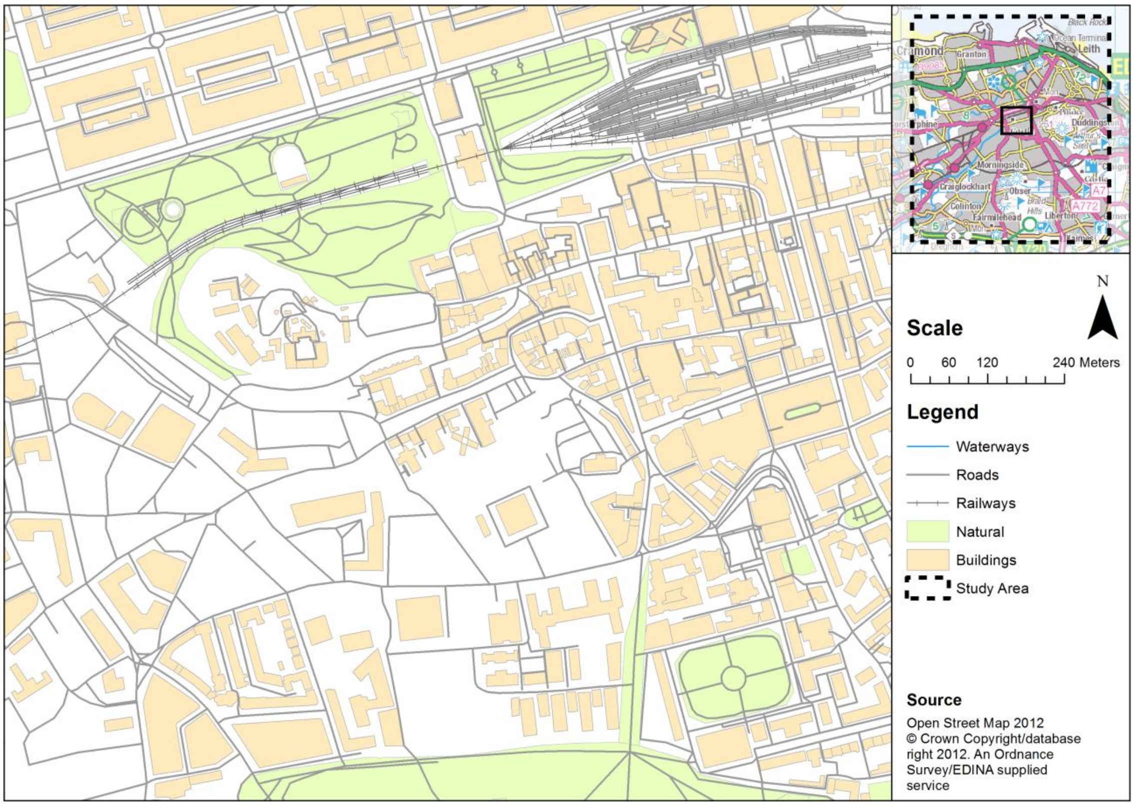


Figure 6.10: Extract of OSM features

6.3 Summary

A large variety of spatial datasets have been gathered together for the use within the development of the pedestrian navigation system, with the aim of creating a richly attributed database of features of interest within the City of Edinburgh. In line with the findings from previous research, outlined in Chapter 2, and the experiments undertaken and detailed in Chapters 4 and 5, this database is then used to quantitatively calculate a value for the saliency of each of the different types of feature of interest (for example buildings, roads, or statues and monuments). This is used, alongside the visibility analysis of the features, to determine the most salient features along a route, both at the primary decision points and as confirmatory points along the route. Additionally, Ordnance Survey's ITN Network for both roads and urban paths are used as the routing network within the system. The creation of the variables measuring saliency are discussed in the next chapter and their implementation in the pedestrian navigation system is discussed Chapter 8.

Chapter 7

Measuring Saliency

Using the technology and data sources outlined in Chapter 6, this chapter sets out the development and creation of variables used to measure the saliency of features of interest. This includes a discussion on identifying the complete set of features of interest for the study area (as specified by the feature classification schema in Chapter 5) from the available data sources outlined in Chapter 6. It then reintroduces each of the saliency categories, as identified in Chapter 4, and discusses the development of variables to measure saliency for each of the saliency categories which can be applied to features of interest identified from the pre-existing data sources. The combination of these variables into a saliency measure and the development of the route descriptions will be discussed in Chapter 8.

The measures of saliency have been developed for three feature classifications - *buildings*, *roads*, and *statues and monuments*. These categories accounted for the majority of features mentioned in the experiments. In *Experiment One* these features accounted for 89 percent of those identified, whilst in *Experiment Two* these three feature classifications accounted for 80 percent of the features mentioned. This is similar to *Experiment Three* which had 82 percent of the features in Route 1 and 91 percent of the features in Route 2 falling into in either the buildings, roads, or statues and monuments category (Figure 7.1). Other features of interest categories such as greenspaces, hills, junctions, and street furniture are discussed, however, due to their lower ranking following the experiments discussed in Chapters 4 and 5, the development of their related saliency measures was not carried through for utilisation in the pedestrian navigation system developed for this thesis.

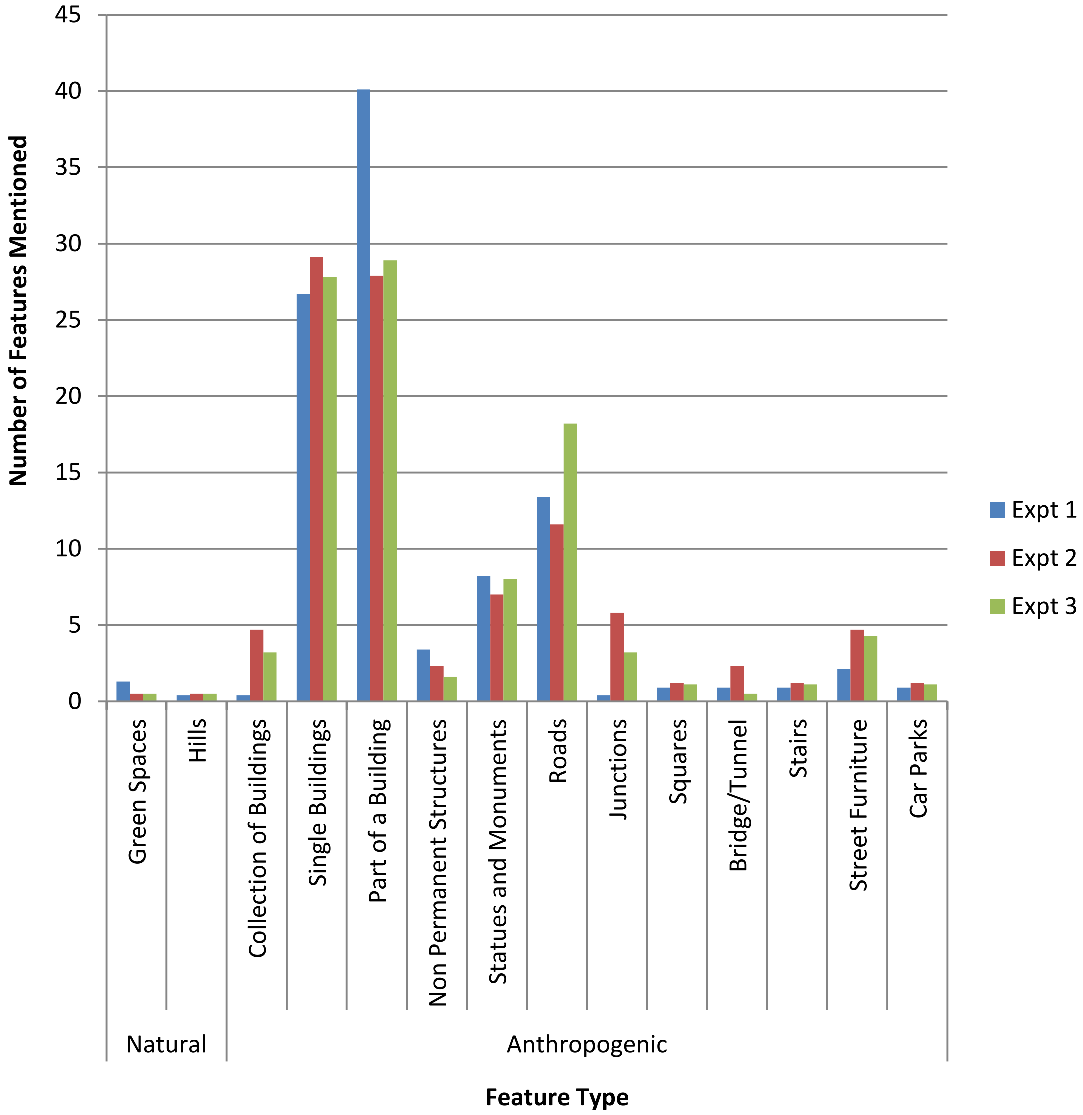


Figure 7.1: The feature types by number of mentions in the three experiments

A number of the variables used to measure saliency were created by combining data from the various sources outlined in Chapter 6, both relationally and spatially. For example PointX's National Points of Interest can be related back to MasterMap through the use of the 'TOID' (TOpographic IDentifier) attribute built into Ordnance Survey data, whilst RCAHMS data and Historic Scotland's Listed Buildings can be linked together with the unique 'numlink' identifier. Additionally, the accuracy of the Gazetteer for Scotland point locations have recently been improved in relation to

Open Source Ordnance Survey and OpenStreetMap data, together with the availability of imagery. This is due to the role the Gazetteer has played in the development of the Definitive Place Name Gazetteer for Scotland, developed by the Scottish Government. The interrelationship and interdependencies of the datasets used within this thesis allows the following variables to be developed with a high degree of certainty.

7.1 Identification of Features

As evidenced in Chapters 4 and 5, a wide variety of features of interest can be used within route descriptions. A classification schema was therefore developed (Figure 5.1) which grouped the features together, in turn, aiding the identification of the variables of saliency that relate to each class of features. In total there were fourteen classification types for the features. The following sections discuss the identification of the spatial features that comprise each of the class types, with particular focus on buildings, roads and paths, and statues and monuments.

7.1.1 Buildings

Buildings are the feature most commonly referred to within route descriptions, as identified by the three experiments. As discussed in Chapter 5, from the experiments it was observed that buildings could be classified into three finer categories: a single building, part of a building, and a collection of buildings. Whilst this is an important observation, it was also observed during development of the building-related saliency measures that the majority of the individual variables were identical between the three classifications. For example, the saliency variables are essentially the same between a single building and part of a building. The difference occurs when looking at the building name in relation to part of a building, as it invariably relates to the occupant of the ground floor space. *Experiment Three* showed that a collection of buildings can be treated as individual buildings, as it is often different buildings within a collection that can be seen from different locations. Each building within a collection is, therefore, modelled as an individual building. The collection of buildings can, in turn, be determined by assigning a common name. In this research, the main example of a collection of buildings is Edinburgh Castle.

The Building Theme Layer within OS MasterMap Topography Layer was used to identify and extract all the buildings within the study area. Data within the Building Theme Layer is defined as “roofed constructions, usually with walls and being permanent” (Ordnance Survey, 2012f, p. 29). Whilst the layer covers roofed buildings, it also covers other physical features such as mobile or park homes that are permanent, archways and covered passageways, horticultural glasshouses, and covered tanks (Ordnance Survey, 2012f).

This data layer provides the most complete set of individual building footprints for the United Kingdom and resulted in a total of 110,983 buildings within the study area. This number was reduced to 83,766 after building footprint’s that had an area 20 square metres or less were removed. It was decided to reduce the number of buildings within the study areas as there were a large number of features that had very small footprints (for example 11,538 building features had areas of less than 10 square metres). The value of 20 square metres was selected as the cut-off point as, upon visual inspection of the data, this was the average size of the bus stop shelters within the City of Edinburgh, which are recorded as building features within the MasterMap Building Theme Layer. Within this research, Bus Stop Shelters are classified as Street Furniture in the classification schema identified in Chapter 5 and therefore are not required within the building feature layer.

Another source of building footprints is OpenStreetMap. However, due to the ‘volunteered’ nature of the data, it is not complete for the City of Edinburgh with only 7975 buildings within the study area (Figure 7.2). Additionally, in many cases individual buildings that are connected to each other are shown as one building rather than as individual buildings (Figure 7.3). For example a number of the blocks of Princes Street are shown as one building outline. Using OpenStreetMap building data would, therefore, affect the quality, validity, and appropriateness of the saliency variables as a finer resolution is required. It is for these reasons that the Building Theme Layer within OS MasterMap was selected for use within this research.

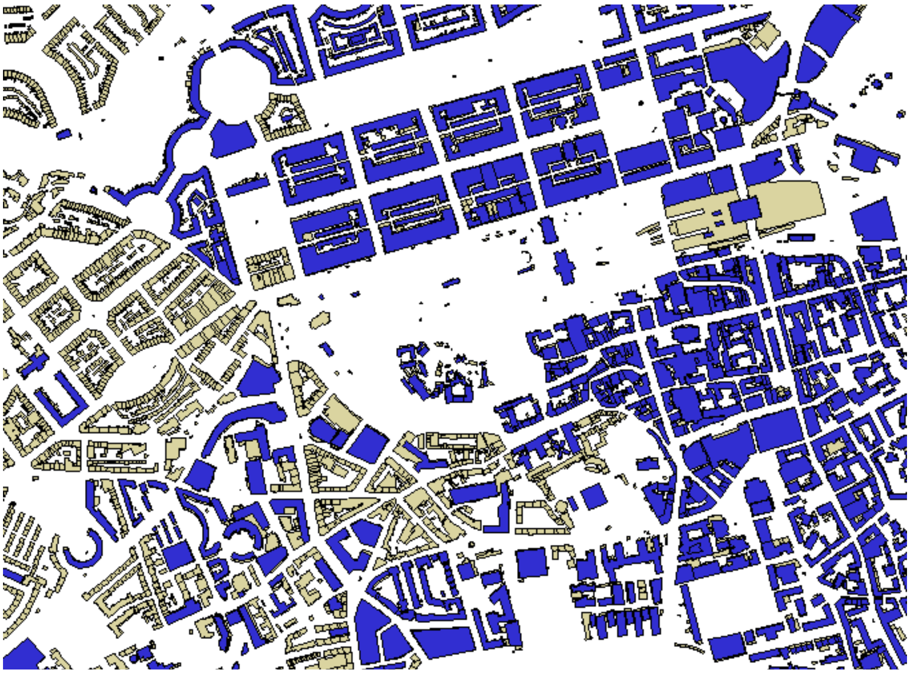
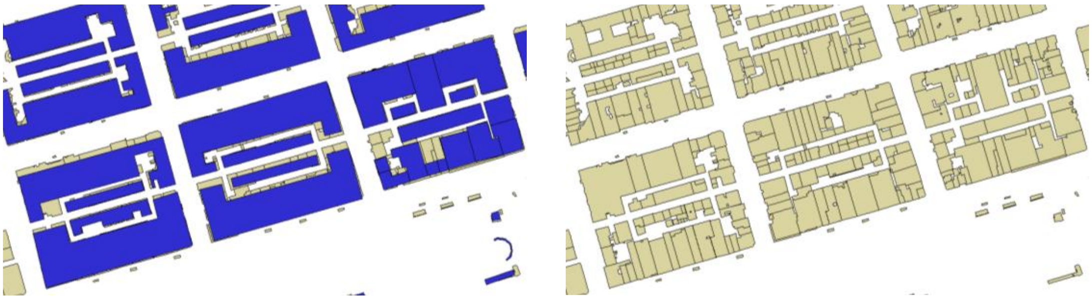


Figure 7.2: OpenStreetMap Coverage compared to OS MasterMap Building Layer Coverage



(a) (b)

Figure 7.3: Differences between the details of the building outlines for (a) OpenStreetMap and (b) MasterMap Building Theme.

7.1.2 Roads and Paths

OpenStreetMap, Ordnance Survey MasterMap and Ordnance Survey ITN Network can all be used to identify road and path features. For this research ITN Network datasets for Roads and Urban Paths was used for the identification of these features. Extraction of data from ITN resulted in a total of 14,158 roads and 7,934 paths within the study area. It was decided to use the ITN Network data as the line features within ITN more accurately reflect the road features than other data sources such as MasterMap, especially in terms of length, and because of the presence of additional information such as feature name and detailed road classifications. Due to the nature of the ITN Network datasets, a single road is split into multiple features where it intersects with other roads. It was, therefore, necessary to dissolve together the road and path line features that had the same name. This allowed the roads and paths to be more accurately represented. Additionally, the features could be related back to the polygon features from MasterMap using the TOID unique identifier. The ITN Road and Urban Paths Network are also used as the basis for the routing functionality, which will be discussed in Chapter 8.

Additional datasets that could have been used for the development of the Roads and Path features include MasterMap Topography Layer. The features could be extracted using the ‘Road and Track’ and ‘Path’ descriptive terms from the Roads, Tracks, and Paths Theme Layer. Using these classifications from MasterMap would have provided all the connecting features such as roads, junctions, squares, bridges, and stairs. However, it was determined that the ITN Network dataset was preferable as it could provide the full road or path and the data from MasterMap was joined to this when required for the development of several of the saliency variables. Within OpenStreetMap extracting all features with an associated ‘Highway’ classification would result in a set of roads and paths, however again due to the volunteered nature of the data, this was found to be incomplete for the study area when compared to the Ordnance Survey data.

7.1.3 Statues and Monuments

A large number of datasets exist that capture the location and information on statues and monuments within Edinburgh. These sources include Historic Scotland’s Listed Buildings, Ordnance Survey MasterMap Topography Layer, PointX’s National Points of Interest, the Gazetteer for Scotland, OpenStreetMap, and the Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS)

stored in the Canmore Database. Each of the datasets were investigated to see which was the most appropriate to use within the pedestrian navigation system.
In MasterMap Topography Layer, statues, monuments, memorials, and other similar features are classified as Structures (Ordnance Survey, 2012e). This could be either as a Topographic Area or as a Topographic Point. Additionally, the Structures Theme Layer for both Areas and Points include more features than simply statues or monuments. For example, structures also represent features such as Telephone Call Boxes, Pylons, Bollards, Letter Boxes, and Triangulation Points (many of these would be allocated to the *street furniture* features of interest classification). Therefore, whilst the Topographic Area Layer can be used for footprints once the complete statue and monument data has been identified, it is not an appropriate data set to use for their initial identification.

Ordnance Survey data has been used in the development of PointX's National Points of Interest data with this reflecting the statues and monuments within the MasterMap layers. The National Points of Interest dataset has a classification for Historic and Cultural Structures which is under the higher classification of Attractions, Historical and Cultural. This dataset identified 127 features for the study area. The Gazetteer for Scotland includes a monument category type, and this resulted in 24 features identified. However, there were only 15 features that existed in both datasets. OpenStreetMap also only yielded 19 features that could be accounted for in the Points of Interest data.

Historic Scotland Listed Buildings have no classification for statues or monuments. The RCAHMS Canmore database has a very detailed classification system with over 1867 sub categories. The initial step for the investigation of these datasets was to identify terms that could be present in the name, description, or classification of a feature that would allow it to be categorised as a statute or monument. Terms identified included statue, monument, memorial, pillar, obelisk, fountain, well, sculpture, or sundial. These words were identified both by inspecting the data and using the descriptions from within the historical and cultural structures classification from the Points of Interest data. Within the Listed Buildings dataset, 92 features were identified compared to the 183 features identified from the Canmore database.

When investigating the sources of data, it became obvious that the RCAHMS dataset was the definitive source of statues and monuments locations as not only did it return a larger number of features, it also contained a number of references to well-known statues within Edinburgh that were missing from the other datasets. For example, three statues that were often mentioned during the experiments were the statues of Adam Smith, James Braidwood, and David Hume which are located on the Royal Mile. These were only present in the RCAHMS data. Additionally, the RCAHMS data provided additional information such as the name of the features and, for a small number of features, age - which will be used in the development of the related saliency measures.

7.1.4 Other Types of Features

Whilst, due to the relative volume of references in the experiments, this research is focused on the creation of datasets, and the development of their associated saliency variables, for only the buildings, roads and paths, and statues and monuments classifications, it is also important to identify methods by which these ideas could be extended to other classification types. Therefore, below is a discussion on the identification of the additional feature of interest type that were not the focus of development within this thesis. In addition, while not included as features of interest in their own right within the pedestrian navigation system, these datasets have been used in some cases to enrich the attribution of the datasets which were included.

Greenspaces and Hills can be identified from both MasterMap Topography Layers and OpenStreetMap. Within MasterMap, natural features can be identified through the use of the Land Theme Layer. Within this theme, there are several different classifications that can be used to identify natural areas - such as selection of all features that have ‘Natural’ specified within the ‘Make’ attribute. The resulting set will include a variety of ‘Natural Environment’, ‘General Surface’, and ‘Landform’ features which are further classified by their vegetation cover type. An issue with using MasterMap is that it doesn't specifically recognise functional sites such as parks or gardens, focusing instead on land use. This means that features such as Princes Street Gardens or The Meadows are divided up into multiple polygons representing different land classifications (i.e. a collection of anthropogenic and natural surfaces) as opposed to representing how individuals in the real world would view such spaces – i.e. a Park (Figure 7.4). Due to this sub-division of natural areas, MasterMap also presents issues when assigning names to the areas. In comparison, OpenStreetMap presents features such as parks, gardens, playgrounds, sports grounds, nature reserves as complete areas, thus more accurately representing how individual would interpret the space in reality. These features can be identified using the 'Leisure' category within the polygon layer. In addition, hills can be located using the points layer and the 'Natural: Peak' classification. Overall, in the context of an individual's perception of space, OpenStreetMap is more suitable for the development of a greenspace and hills dataset.

(a) (b)

Figure 7.4: Differences between West Princes Street Gardens as represented by (a) MasterMap Land Theme and (b) OpenStreetMap

Junctions are defined as "a confluence of roads" (Ordnance Survey, 2012e, p. 261) and are, therefore, best identified by using the point of intersection of the road network. The road network, as discussed above, can be gathered from Ordnance Survey's ITN Network or OpenStreetMap Road Network. Using either of these networks it is possible to incorporate or limit the features of the network to those that are required. For example, inclusion or exclusion of features such as paths, footbridges, or stairs can be determined within the definition of a junction. Junctions can also be referred to as decision points.

Squares are “an open area within a built-up area bounded by several streets” (Ordnance Survey, 2012e, p. 473) and are often only defined in MasterMap Cartographic Layers - the layers providing annotation to MasterMap. In general, they are included within the Roads, Tracks and Paths Theme Layer. These features can therefore be extracted from MasterMap by selecting those annotations that include square (or ‘sq’) within the textual information and then intersecting them with the Roads, Tracks and Paths Theme. Other sources include the Gazetteer for Scotland which provides a short list of squares within Edinburgh. The point location associated with these entries can be intersected with the MasterMap Roads, Tracks and Paths to provide a set of features. In OpenStreetMap, squares can be identified by using the category ‘Highway: Pedestrian’. This represents pedestrianised areas, however, they can act as a good representation for squares. OpenStreetMap returns good coverage of squares within the study area (47 in total) especially in the area surrounding the Royal Mile.

Bridge, Tunnels and Stairs can be identified through the ITN Roads and Urban Path networks. Each of the datasets contains environmental qualifiers that represent bridges and stairs. Within ITN Roads the qualifier is ‘Bridge over Road’ whilst in ITN Urban Paths the qualifiers are ‘Footbridge’ and ‘Steps’. Selecting these qualifiers identifies the feature set for bridges and stairs. OpenStreetMap can also be used to extract these features of interest with stairs being identified using the ‘Highway: Steps’ category and bridges identified using the ‘Bridge’ category.

Street Furniture refers to features such as police boxes, telephone boxes, recycling stations, bicycle parking, and bus shelters. All of these features can be readily identified from a large variety of datasets including (and not limited to) OpenStreetMap, MasterMap Topography Layers, PointX’s Points of Interest, and Historic Scotland Listed Buildings. The MasterMap layers again overlap significantly with the features in the Points of Interest data whilst Listed Buildings include references to protected telephone boxes and police boxes. Points of Interest and OpenStreetMap datasets allow for the identification of a wide range of additional features that were not identified from the three experiments such as bus stops, grit bins, cash machines, letter boxes, and public toilets. The most suitable data sources for use in the creation of a Street Furniture feature dataset were determined to be OpenStreetMap or the National Points of Interest, selecting the appropriate classifications from each.

Carparks are best identified using either OpenStreetMap (searching for classification type Parking) or the National Points of Interest data (using the classification Transport, Road and Rail, Parking). There are currently 62 car parks in the Points of Interest data and 60 car parks in OpenStreetMap for the study area.

Non Permanent Structures would be required to be gathered from a variety of sources such as Edinburgh Council, for major building works and road works, and individuals or websites associated with special events - such as the Edinburgh Fringe Festival organisers to find out the location of all the fringe venues (temporarily erected or a building with a changed name, use or function for the duration of the Festival). There is a high level of complexity associated with creating this dataset, with continuing updates to the dataset required. The location of road works is accessible from Scottish Road Works On-line which provides the public with access to information about ongoing road works within Scotland on behalf of The Office of the Scottish Road Works Commissioner (The Office of the Scottish Road Works Commissioner, 2012). After the features have been identified their related saliency variables would be calculated in relation to their closest classification. For example, temporary structures would be treated as buildings, road works treated as roads. They would then be assigned a high rating in the temporality saliency category.

7.1.5 The Feature Datasets

The buildings, roads and paths, and statues and monuments feature datasets were created using the methods discussed above in Sections 7.1.1-3. Each dataset was stored as a separate layer, with buildings represented as polygon features, roads and paths as line features, and statues and monuments as point features. Each of the three datasets were then attributed with their related saliency variables.

The following sections discuss the development (or theoretical development) of the variables measuring the fourteen saliency categories identified in Chapter 4 for each of the three main categories identified above; Buildings, Roads and Paths, and Statues and Monuments. The sections below also contain brief discussions on how the saliency variables could be created for the other feature classifications (such as greenspaces, hills, or street furniture) that were deemed to be out with the scope of this research. Key to the development of the saliency variables was the necessity to reduce each variable to a numerical value, in order for a quantitative value of overall saliency to be calculated.

7.2 Name Saliency

The experiments showed that Name was the most important measure of saliency. Individuals can often refer to a feature of interest directly using its associated name without the additional need to clarify the feature with a description. Many features of interest, especially buildings, statues, and monuments, are clearly labelled, therefore if a feature has a name in the dataset, it should be more highly rated than one that doesn't. Additionally, the identification of names for features of interest is important for the incorporation within route directions.

7.2.1 Buildings

The names of buildings were initially created using the Gazetteer for Scotland. For those buildings that were still without a name, PointX's National Point of Interest data was used. PointX allowed for the identification of shops and commercial names, along with restaurants and bars. In using the Points of Interest data however, it was necessary to remove a large number of classifications for objects that existed within buildings yet were not the main function of the building. Examples included wifi hotspots, cash machine, and public telephones. A building was then intersected with the resulting Points of Interest dataset and if there was only one feature it was assigned the name of that occupant. If there were two or more occupants it was assigned the name of the first two occupants listed, in order to allow two options for identification.

7.2.2 Roads and Paths

Names of the road and path features were gathered from the routing information associated with the ITN Network data. Of the 14,158 roads only 1,735 did not have associated names. Within the features without names, 60 percent were classified as private roads and 32 percent were classified as local streets. Only 339 of the 7,934 paths had associated path names. On inspecting those paths that were not assigned names through the ITN data, it was observed that a number of them were paths through green spaces such as parks or gardens. Therefore, using the green space feature dataset (created as discussed in Section 7.1.4) the paths were intersected with them and assigned a name of 'Path through' and the name of the green space. Examples of path names created include Path through Inverleith Park, Path through Princes Street Gardens, and Path through Corstophine Hill Local Natural Reserve. Additionally, features that were described as a cycle or canal path or as steps they were given the name of 'Cycle Path', 'Canal Path', or 'Steps'. This added name features to an additional 1,239 path features. This name variable could be enriched by the inclusion of vernacular names, such as referring to the 'Royal Mile' rather than to the High Street, however a dataset detailing such names which would allow for automated inclusion does not at present exist.

7.2.3 Statues and Monuments

Statues and monuments were identified using the RCAHMS Canmore database which provides not only the location of the statues and monuments but also their names. The names are included within the site name field which generally comprised a common format with the name of the statues last. This formatting of the fields allowed for the names to be readily extracted.

7.2.4 Other Types of Features

For other features classifications the name saliency variables could be calculated through a number of different means. The names of *Hills* can be gathered from either OpenStreetMap or the Gazetteer for Scotland whilst a number of *Green Spaces* would inherit names from the creation of the feature set from OpenStreetMap. The name of *Squares* can be determined from OpenStreetMap or MasterMap layers whilst the name of *Street Furniture* would generally be related to the type of feature it is, such as telephone box or police box.

7.2.5 Classification of Saliency Variables

For use within the saliency model, all variables are converted to values. Features were assigned a value two if the name was pre-assigned by the dataset, a one if it was calculated, and zero if a name didn't exist (Table 7.1). This reflects a higher value for the values that are determined to be more salient, in this case having a name present.

Value	Definition	Features
0	Name not present	Buildings Roads & Paths
1	Name created using additional data sources	Roads & Paths
2	Name present in original dataset	Building Roads & Paths Statues & Monuments

Table 7.1: Name saliency variable classification

7.3 Size Saliency

Size saliency relates to the physical size of the features. This can be the area, volume, or height of a building, the width or length of a road, or the size (large or small) of a statue. Raubal and Winter (2002) included size of façade area, Elias

(2003b) used the area of a building, whilst Ganitseva and Coors (2010) used height and façade area.

7.3.1 Buildings

Four variables can be calculated for buildings with regard to the size saliency variable: area, height, volume, and façade area (Figure 7.5).

Area of a building footprint was calculated within a PostGIS database by using the *st_area* function.

Height was calculated using the zonal statistic tool within ArcGIS. This tool takes each building footprint and calculates the average value of the cells of a raster grid that intersect with the footprint. This tool was used twice, once for the DTM grid and once for the DSM grid. An average height value was then calculated by subtracting the DTM value from the DSM value. Several tests were carried out to verify the height measurements. The heights were compared against a set of heights that were generated using the same methodology from a LiDAR dataset that was flown in 2001 of the Old Town, Edinburgh. There were minimal differences between the two sets of calculated building heights. The differences could be attributed to buildings either being demolished or built. Testing was also completed by comparing reported values of height from the Gazetteer of Scotland and Canmore to those generated from the LiDAR data. No rigorous testing of the height calculations was undertaken against real world measurements. This was because the height calculation was being used to allocate different classes of height to buildings.

Volume was calculated by multiplying average height and footprint area together.

Façade Area is generally treated as a rectangle calculated from the width of the façade multiplied by the building height (Raubal & Winter, 2002). Nothegger *et al.* (2004) calculated façade area in terms of shape deviation. If a façade had a shape deviation (from a rectangle) greater than zero, then the façade was manually outlined and the area calculated. Within this research, façade area has been calculated using the Topographic Line features from MasterMap. Within this dataset, lines are classified based on the two different theme types that the line intersects. Using the Building and Roads, Tracks, and Paths Themes, the length of the façade that is adjacent to a road or roadside (pavement) can be calculated. This returns the total length of a building façade which occupies a road. If a building is on a corner, the façade length of both sides would be included in the calculated value. This length is then multiplied by the height of the building to provide its overall facade area.

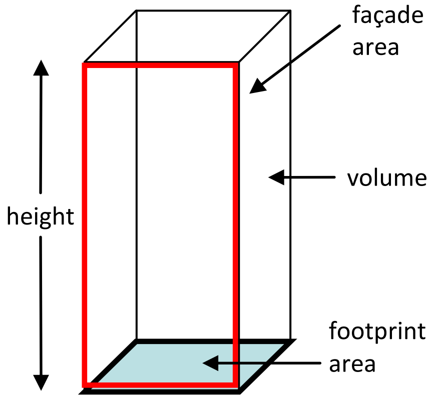


Figure 7.5: The four size saliency measures for a building feature

7.3.2 Roads and Paths

Three variables can be calculated for roads and paths with regard to the size saliency variable: length, area, and width.

Length is generated by calculating the length of the line that represents the road and path features. This used the *st_length* function available in PostGIS.

Area is calculated by intersecting each of the roads and paths line features with the Roads, Tracks, and Paths Area Theme Layer from MasterMap. Within this layer, each road and path is represented as a polygon feature for which its area can be calculated. The aggregation of the areas of polygons that a particular road or path line feature intersects with gives an approximation of the total area of the road (Figure 7.6).

Width is calculated using the assumption that the roads are rectangular. This assumption allows the width of a road to be calculated by dividing area by length. This provides a general approximation on the width of the feature. This width measurement provides an estimation of the width of roads. It does not take into account the width of the footpaths associated to the road and so will underestimate the overall perception of the width of a road. This underestimation is evident from Figure 7.6 where the road is only approximately half the size one would expect. The calculation of width could therefore be improved if not only the road polygons that intersect with the road line feature are selected, but also those footpath features that border the road polygons.

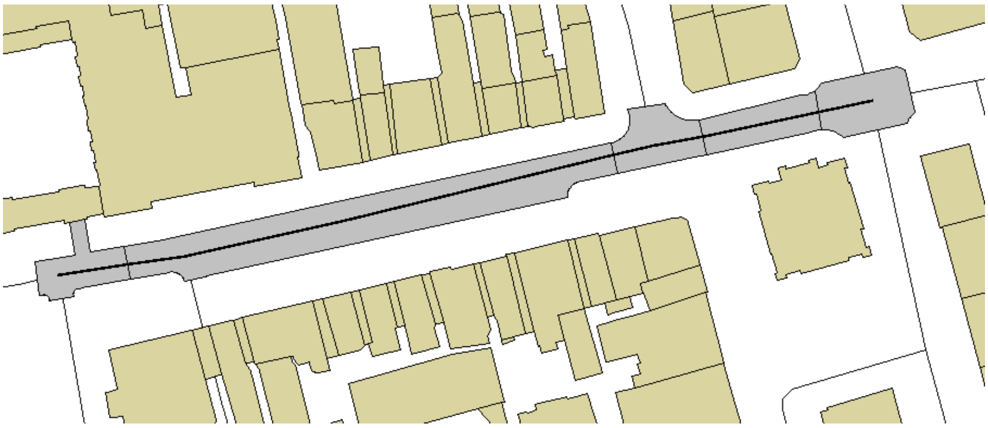


Figure 7.6: The area and width saliency measures for a road and path feature. The grey polygons represent the area.

7.3.3 Statues and Monuments

Two variables can be calculated for statues and monuments with regard to the Size saliency variable: area and height.

Area can be calculated for a very small subset of statues and monuments though the intersection of the statues and monuments features with the Structures Theme Polygon Layer within MasterMap Topography Layer. The statues that are stored within MasterMap are those that have been deemed large enough to capture. For monuments, MasterMap captures all features greater than 8m^2 as polygons (Ordnance Survey, 2012e). The features that have a footprint available within

MasterMap have been assigned an area value. Within the statues and monuments dataset 68 features (37 percent) intersect or are within five metres of a Structure feature from MasterMap. The buffer distance was chosen as all of the statues and monument features had a stated accuracy of five metres or less.

Height is calculated by intersecting the point location of the statues and monuments with the both the DTM and DSM and then subtracting the DTM value from the DSM value. This provided a height value for the statues and monuments. This method approximates the height of a statue or monument - bigger statues will be identified within the LiDAR data, however, smaller statues may not and the height value may reflect the height of the plinth rather than the statue as a whole. The issues associated with calculating the height of statues are the same as with the height calculations for buildings. However, the major issue with extracting the height of statues from LiDAR is the resolution of the data. The LiDAR data used has a resolution of two metres and therefore the accuracy of this measure relies on the accuracy of the location of the point feature. This method provides a best approximation for the height of statues.

In future, the textual searching of the RCAHMS Canmore database within the associated architectural and field visits notes would allow for more detailed information about the size of a statue or monument, however, this information is not captured for all features.

7.3.4 Other Types of Features

For the other features types, not implemented within the pedestrian navigation system, the size variables could also be calculated. For *Greenspaces and Hills* and *Squares,* both polygon features identified by OpenStreetMap, an area can be calculated. *Street Furniture* could be assigned area and height values based on the type of feature it is. For example telephone boxes and police boxes are consistently the same size across Edinburgh and therefore their size variables could be inferred from this. *Carparks* are point features, therefore determining their extent requires a spatial join between this point data and MasterMap Topography Layer to retrieve its area.

7.3.5 Classification of Saliency Variables

Each of the variables related to size saliency is stored as its numeric value (Table 7.2). This allows for the comparison and identification of a feature that is an outlier in terms of size (large or small) within the surrounding area. The application of this is discussed in Chapter 8.

Value	Definition	Features
Area		
Numeric Value	The calculated area value	Buildings Roads & Paths Statues & Monuments
Height		
Numeric Value	The calculated height value	Buildings Statues & Monuments
Façade Area		
Numeric Value	The calculated façade area value	Buildings
Volume		
Numeric Value	The calculated volume value	Buildings
Length		
Numeric Value	The calculated length value	Roads & Paths
Width		
Numeric Value	The calculated width value	Roads & Paths

Table 7.2: Size saliency variable classification

7.4 Age Saliency

Age is referred to generally as either ‘old’ or ‘new’. Raubal and Winter (2002) argue that age is part of the condition of a building and that whilst it is possible to determine the age of a building in the real world it is problematic due to renovation works taking place. This is very true of Edinburgh, where new buildings are often built to look old and old buildings are often being refurbished. For example, the

Raddison Hotel on the Royal Mile looks medieval but was built in 1990s and Adam House, which looks like it was built in the 18th Century, was actually built in the 1950s. This means that modelling the age of buildings and statues and monuments is quite complex. Using architectural information, such as classical, modernist, or art deco could provide a method of determining what a building is meant to look like without requiring a specific age. This is still quite a difficult variable to determine as discussed in Section 7.10. However, consideration of age has proved to be extremely important to the participants of the experiments and as it can possibly reflect on the condition of a feature (another important saliency category that is more subjective) it is included within this research, focusing on the date that the feature was built or erected. The assignment of the age saliency will vary within different urban settings. Within Edinburgh many features are referred to as old due to the historical nature of the city. Within newer cities (such as cities in America, Australia or New Zealand) the date at which a feature is classed as old would need to be readdressed as individuals impression of old versus new buildings will change due to the makeup of the city and its history.

7.4.1 Buildings

Both RCAHMS's Canmore database and Cities Revealed Building Class dataset can be used to calculate the age variable for buildings. From the Canmore data, a number of the sub classifications include a reference to the period in which the feature was built (such as 19th Century or 21st Century). For those RCAMHS features that fall within building footprint, the period information is extracted and added as an attribute of the building feature dataset. This results in 3,289 buildings being assigned an age value. This provides an approximate age for the building. It should be noted that the RCAHMS dataset records the oldest age associated with a building, for example a building may have a 17th Century core, but it could have been extended or refurbished and look different from its original age. However, this data is the best approximation available for the age of buildings.

The Building Class dataset provides an estimation for the age of buildings. The data are provided in a coarse resolution, with many features covering whole blocks of buildings and applying the same value across them. It is due to the coarseness of this data that it is used to supplement the data from RCAHMS. Additionally, the building class data only covers building areas that are deemed to be residential. If a building feature intersects with a building class feature then the building feature was assigned the relative age classification. This assigns an age value to an additional 70,277 features. This resulted in 10,200 building features (12 percent) not being assigned an age value.

7.4.2 Statues and Monuments

The age of a quarter of the statues and monuments within the study area can be determined using both the RCAHMS Canmore database and the Gazetteer for Scotland. As with the buildings, the Canmore data provides period details within the sub classification for a sub set of the features. This information is extracted into an age attribute of the statue and monuments dataset. The Gazetteer for Scotland includes the date that a monument was erected. This date value was extracted from the Gazetteer and incorporated into the age attribute. This resulted in 46 of the 183 statues and monuments features being assigned an age value.

One way of increasing the coverage of age would be to use the field visit notes section from the Canmore database where the year of unveiling is recorded. Not all statues and monuments, however, have had site visits completed.

7.4.3 Other Types of Features

The age saliency measure is only applicable to a few of the other features types. Age is not relevant to *Connecting Features* as it was never mentioned in relation to roads, bridges, junctions or squares. *Non-Permanent Structures* would be classified as new whilst *Street Furniture* and *Carparks* would likely all be relatively new in comparison to the buildings, especially with regards to the City of Edinburgh.

7.4.4 Classification of Saliency Variables

Two boolean measures were developed with regard to the age saliency category: old and new (Table 7.3). A building was classified as old if it was built in the 19^{th} Century or earlier or was classed as either 'Historic to end Georgian', 'Early and Middle Victorian', or 'Late Victorian/Edwardian' – information derived from the building class data from Cities Revealed (Cities Revealed, 2010). A statue was classified as old if it was constructed in the 19^{th} or 20^{th} Century. This will unfortunately treat a statue erected in 1999 as old, however, this was deemed preferable to suggesting a statue erected in 1901 was new. More detailed age data for statues is required to provide a better classification for age.

Buildings, on the other hand, are classified as new if it was built later than 1979. It was decided to use 1979 as the cut-off point based on the 'Recent Years' building class category from Cities Revealed (2010). This allowed for consistency in the way that the new value was calculated across buildings and statues and monuments.

Value	**Definition**	**Features**
Old		
0	No (or no age value available)	Buildings, Statues and Monuments
1	Yes	Buildings, Statues and Monuments
New		
0	No (or no age value available)	Buildings, Statues and Monuments
1	Yes	Buildings, Statues and Monuments

Table 7.3: Age saliency variable classification

7.5 Colour Saliency

In this research, colour relates specifically to buildings though it is rare that the building is the same colour across its entire façade. When the colour varies over the building it specifically relates to the colour of the building at pedestrian level. This façade colour may reflect the construction material of the building. A number of authors have noted that façade colour plays an important role in the visual discrimination of features (Ennesser & Medioni, 1995; Wolfe, 2000). Raubal and Winter (2002) included this as a measure within their formal model of saliency. This is an extremely hard variable to attempt to automate. Nothegger *et al.* (2004) developed a manual method for the calculation of façade area, which required the manual identification of a façade area from a photograph within Adobe Photoshop. The software then calculated the median RGB values and converted them to the HSB colour model to determine the average colour of the façade. A possible method for automating this variable would be to use image processing algorithms extract the façade colour (in additional decoration, signage, and building condition) using Google's Street View imagery. This method, however, is not undertaken within this thesis.

7.6 Emotion towards Features Saliency

Emotion towards a feature is a very interesting variable; one that is very subjective and extremely difficult to calculate. This is a measure of saliency that has not previously been discussed before in the literature. Participants in the experiments had contrary views; some had a positive view of a feature whilst others expressed negative views. This variance between individuals adds to the difficulty in modelling this aspect of saliency.

Within this research this measure is not calculated, however, in the future it could be measured through user intractability with the pedestrian navigation system. For individual features, users could specify whether they viewed the feature positively (i.e. it is 'nice', 'attractive', or 'beautiful') or negatively (i.e. it is 'ugly', 'horrible', or 'hideous'). These ratings could then be averaged over the number of responses and features that have high positive or negative feelings could be classified with the value of one and added into the saliency calculations. Another method which could be applied to incorporate an individual's emotions towards a feature could take the views of the person towards different types of features into account and use these to limit the information reported back in the route descriptions. This would allow the route descriptions to be tailored specifically towards the needs of the navigator by using those features that they find attractive or think positively of within the urban environment.

7.7 Decoration and Signage Saliency

Decoration and Signage is similar to Raubal and Winter's (2002) explicit marks measure. This refers to whether there is any unique decoration or signs on the feature, such as stained glass windows, a coat of arms, or the name of the restaurant or bar. It can also refer to the different decorations on a monument.

The extraction of the decorative details on a building, statue, or monument is extremely difficult. Methods could possibly be developed to extract this information automatically from photographs of features, or from Google Street View. The existence of signage on a building, however, can be approximated. The method used within this thesis is based on the identifyability measure developed by Nothegger *et al.* (2004). Nothegger *et al.* measured identifyability on the follow four level scale:

0. No marks
1. Building is used commercially
2. Building is used commercially, by a category of usually well marked ventures (restaurants etc.)
3. Building is used by well known international (retail/food/hotel) chain

7.7.1 Buildings

If an occupier of a building is a commercial venture then it is assumed that there is signage somewhere on the façade of the building. If the feature is a company that is normally well marked such as a restaurant, bar, retail shop or if it is a company known internationally, it raises the saliency of the feature.

To create the signage saliency variable, PointX's National Points of Interest were used. From this dataset, if a building had an occupant that was classified at the highest level as either 'Commercial Services' or 'Sport and Entertainment' it was assigned a value of one. A building was assigned a value of two if one of its occupants was classified as 'Accommodation, Eating and Drinking' or 'Retail'. Finally, a subset of the Points of Interest based on a list of well known, multinational companies was created. If a building had one of these companies as an occupant, it was assigned a value of three (Table 7.4). Multinational occupancy receives the highest value due to the increased likelihood of recognisability for people not familiar with an area – i.e. the Starbucks or McDonald's logos. This increases the utility of the pedestrian navigation system and its applicability to other locations.

Value	**Definition**	**Features**
Signage		
0	No marks	Buildings
1	Commercial Service or Sport and Entertainment occupant present	Buildings
2	Accommodation, Eating and Drinking or Retail occupant present	Buildings
3	Multinational occupant present	Buildings

Table 7.4: Signage saliency variable classification

7.8 Location Saliency

The category of location saliency aligns with the research conducted by Elias (2003a, 2003b) and Brenner and Elias (2003). Their work identified 19 saliency attributes for buildings, nine of which related specifically to its location in the environment. These location attributes included whether a building stood alone, was connected to its neighbours, the distance the building was from the road, the density of the buildings in the neighbourhood (defined as an area of $100m^2$), and the orientation of the building. The description of these attributes was purely theoretical and they were illustrated with synthetic building data that had the attributes manually calculated.

Within this research, several variables based on this work were calculated including the location of a feature in relation to a decision point, the location of a feature in respect to a road, and whether a building stands apart from other building features.

7.8.1 All Feature Types (except Roads and Paths)

The ***Location in Relation to a Road*** variable is generated using the method outlined by Elias (2003b) for the 'Building moved away from street' attribute. This calculates the closest distance (in metres) a building is to the road. If the distance calculated is zero, it is said to be located on the road and is assigned a value of two. If the feature is within ten metres of a road it is said to be close to a road and assigned a value of one. All other features are said to be far from a road and are assigned the value of zero (Figure 7.7, Table 7.5).

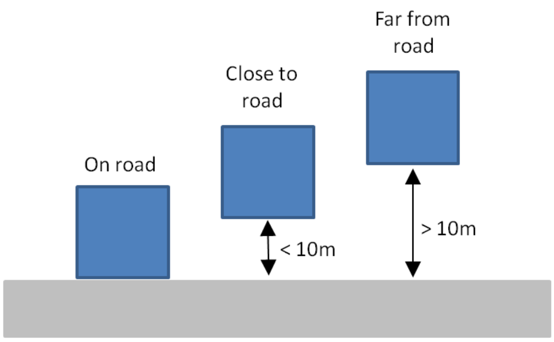


Figure 7.7: The calculation of the variable measuring location in relation to a road

The ***Location to Decision Points*** variable identifies if a building is within a set distance of a decision point. A decision point is defined as any place where two or more roads or paths intersect. This is used as an approximation for a corner. The distance between each feature and their nearest decision point is calculated in metres for this variable. If a feature is within 15 metres of a decision point it is assigned a value of two, within 30 metres of a decision it is assigned a value of one, otherwise the feature is said to be far from a decision points and assigned a value of zero (Figure 7.8, Table 7.5).

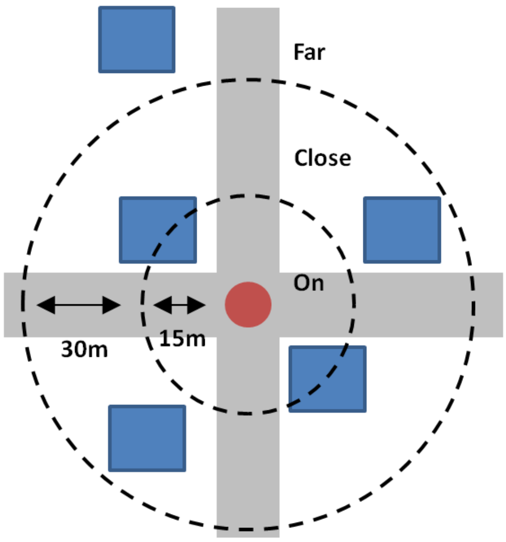


Figure 7.8: The calculation of the variable measuring location in relation to a decision point

The ***Building Stands Alone*** variable identifies whether a building is joined to another building or whether it is surrounded by open space (Figure 7.9). This is calculated using the Topographic Line Layer from MasterMap. Within this layer, line features that are related solely to a building can be extracted. These line features are attributed with the 'description term' of either 'outline' or 'division'. A line is classified as a division if the joining buildings can be identified as separate from one other. Therefore, any building feature that intersects with a line classed as a division can be identified as being adjacent to another building; those buildings that do not intersect can be classified as standing alone. If a building is adjacent to another building it is assigned a value of zero whilst if is apart from other buildings it is assigned a value of one.

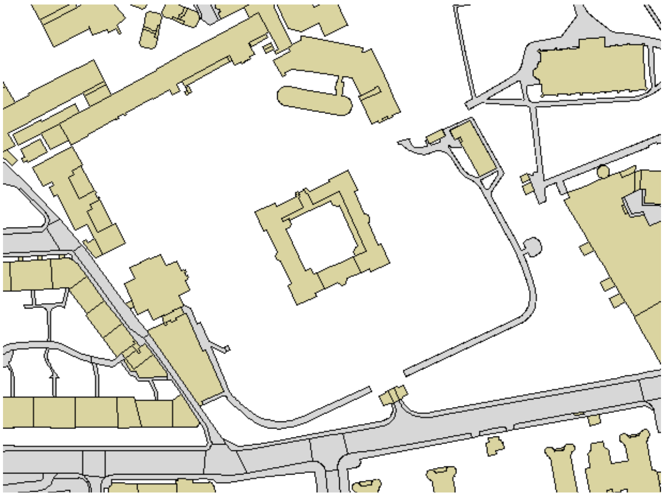


Figure 7.9: George Heriot's School illustrating the building stands alone variable

Value	Definition	Features
Location to a Street		
0	Far from Street	All Features (excluding Streets)
1	Close to Street	All Features (excluding Streets)
2	On Street	All Features (excluding Streets)
Location to a Decision Point		
0	Far from Decision Point	All Features (excluding Streets)
1	Close to Decision Point	All Features (excluding Streets)
2	On to Decision Point	All Features (excluding Streets)
Building Stands Alone		
0	Building is adjacent to another Building	Buildings
1	Building Stands Alone	Buildings

Table 7.5: Location saliency variable classification

7.9 Construction Saliency

Construction refers to the material that the feature of interest is constructed from. In terms of a building this could refer to either the material of the entire building (such as sandstone or concrete) or to just the material of the façade (such as glass). For streets, the construction material specified was cobbles. This is a variable that is problematic to automatically generate, to the extent that it could not be modelled for saliency with the datasets currently available. One method that could be used is the word-based searching of the Gazetteer for Scotland with words such as ‘sandstone’, ‘glass’, ‘façade’, and ‘brick’. If these words are located within the description, however, the text would need to be interpreted to ensure that it was in fact talking specifically about the feature that was required. When searching the Gazetteer for the word ‘glass’ it brings back 26 results, only two of which refer to the construction material of the façade. Another method could be the textual searching of the RCAHMS Canmore database for those building features that are included that have had field visit conducted. They may be able to report information on the construction material. Finally, as with several of the other saliency categories, this information could also be collected through public participation with individual reporting to the pedestrian navigation system the construction materials of buildings and whether a road is cobbled or not.

7.10 Architectural Saliency

Architecture was only mentioned by the experiment's participants in relation to buildings and refers to the architectural style of the building, such as Georgian, Modern, or Classical. The style of a building, in the majority of cases, can be related back to the date it was built (i.e. its age). The ideal way of developing this variable would be to identify the architecture type of each building. This information is not commonly available. For a very small subset of building features this information can be extracted from the Gazetteer for Scotland. However, as this resulted in less than fifty buildings being allocated an architectural type, it was determined that a more encompassing variable was required.

7.10.1 Buildings

Another way of measuring the architectural saliency of a feature with the available datasets would be to use Historic Scotland's Listed Buildings. Building features can be listed by Historic Scotland if they are of architectural interest or due to their age and rarity. Unfortunately, the precise reason why a building has been listed is unavailable from the dataset. This is, therefore, used as a proxy for architectural saliency. If a building is listed, it is assigned a value of one, two, or three based on the Listed Building categories of C(S), B, and A (Table 7.6). It should be noted that, this measure is also included as one of five variables measuring cultural and historical saliency of features.

Value	**Definition**	**Features**
Architectural Importance		
0	Not a Listed Building	Buildings
1	Listed Building - Category C(S)	
2	Listed Building - Category B	
3	Listed Building - Category A	

Table 7.6: Architectural saliency variable classification

7.11 Function Saliency

Buildings were more often mentioned if they were related to a specific function or use. Those functions that were identified as important from the experiments in Chapter 4 and 5 included restaurants, bars, hospitals, schools, and public buildings (such as court houses or libraries). The use of a building was identified as a measure of saliency by Elais (2003a, 2003b) who classified buildings functions into four groups: residential, public, underground, and outbuildings. This classification was not adopted as from the experiments it was observed that more specific functions were being identified by the participants, including restaurants and bars and public buildings such as court houses and libraries.

7.11.1 Buildings

Within this research, the classifications used were residential, commercial, public, and eating and drinking establishments. If a building feature intersected with the Cities Revealed building class feature then the building feature is assigned a value of one representing the residential classification (Table 7.7). This is based on the statement that the building class dataset only covers residential areas (Cities Revealed, 2010). This step is completed first due to the coarseness of the building class; it covers the whole areas which may also include commercial properties. Therefore, if a building has already been assigned a residential classification it will then be altered when the more precise PointX data is used.

Value	Definition	Features
Function Importance		
0	No Function Assigned	Buildings
1	Residential Buildings	
2	Commercial Buildings	
3	Public Buildings	
4	Eating and Drinking Establishment	

Table 7.7: Function saliency variable classification

For the commercial, public, and eating and drinking classification PointX's National Points of Interest were used. For each of these three classifications a list of the relevant classifications from PointX was created. If a building had an occupant that had one of the classifications from PointX it was assigned the corresponding function classification. If a building was classified as a restaurant by PointX, it would be classified under the eating and drinking function and the building would be assigned a value of four (Table 7.8).

Function Classification	**PointX Classifications**
Commercial	Commercial Services Sport and Entertainment Attractions - Historical and cultural - Tourism Accommodation, Eating and Drinking - Accommodation Retail
Public	Public Infrastructure: - Central and Local Government - Infrastructure & Facilities (Libraries, Places of Worship Education and Health: - Primary, Secondary and Tertiary Education - Health Practitioners and Establishments - Health Support Services
Eating and Drinking	Accommodation, Eating and Drinking - Eating and Drinking

Table 7.8: Breakdown of Function Classifications by PointX Classifications

7.11.2 Other Types of Features

For the other features types, not addressed in this research, function could be assigned to *Greenspace* features by assigning a value to reflect the use of the area, such as park, garden, or playground. The function of a *Carpark* feature is obvious, whereas the function of *Street Furniture* can be inferred from its name (such as bus stop or telephone box).

7.12 Shape Saliency

Shape can refer to either the shape of a building or the shape of the road. Several authors have included measures of shape deviation and complexity as measures of saliency. Raubal and Winter (2002) calculated the shape factor of buildings and the shape deviation of façades (measuring the deviation between the façade shape and a rectangle). These two measures were extended by Musliman *et al.* (2010) for the calculations of shape saliency for 3D objects. Finally, Elias (2003a) used the number of corners (or quoins) to measure shape complexity. Within this research, it was determined that the complexity of shape and its deviation from a rectangle were important to measure the saliency of buildings, whilst the complexity of a road and path was also calculated. The use of footprint shape, rather than facade shape, was determined from the three experiments. When participants were discussing the shape of features they were often focussing more on its full physical shape rather than the shape of the building's facade. It was mostly the footprint shapes of buildings that caught the attention of the participants.

7.12.1 Buildings

Shape Deviation is measured based on the formula used by Raubal and Winter (2002). This is, however, applied to a building footprint rather than a building façade. It was decided to use footprints as many of the descriptive words collected from the experiments described the shape of the buildings rather than the façades. Words used included 'rectangular', 'blocky', 'squarish', 'circle', and 'circular'. Shape deviation is calculated with the minimum bounding box around the building footprint and then using the following equation:

$$\frac{\text{area of minimum bounding box} - \text{area of building}}{\text{area of minimum bounding box}}$$

This gives the percentage difference between the bounding box and the building footprint (Figure 7.10). If there is no difference the shape deviation will be zero.

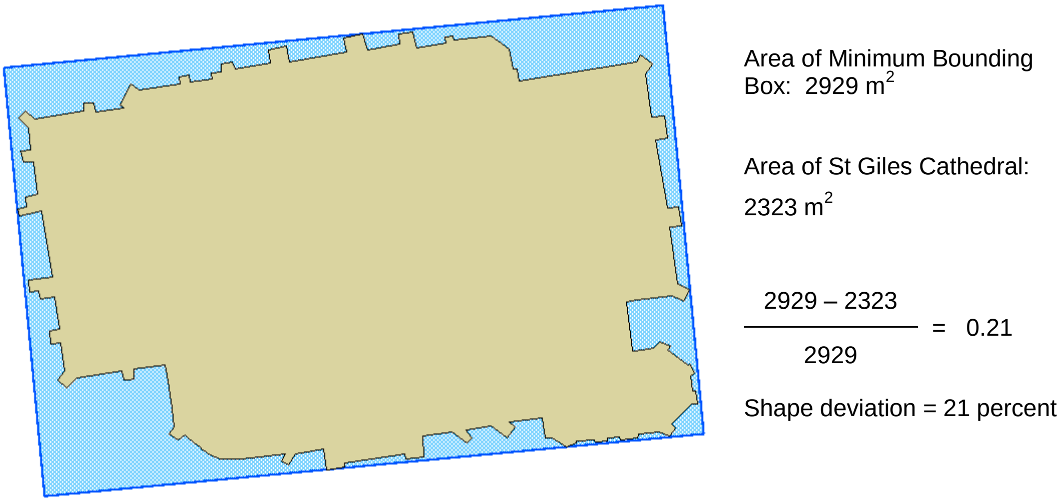


Figure 7.10: The calculation of the variable measuring shape deviation for St Giles Cathedral

The ***Shape Complexity*** calculation is based on the method developed by Elias (2003). This calculated the number of corners a building feature has. This was calculated by extracting the number of vertices that a building footprint polygon has (Figure 7.11). This acts as an approximation for the number of corners of a building.

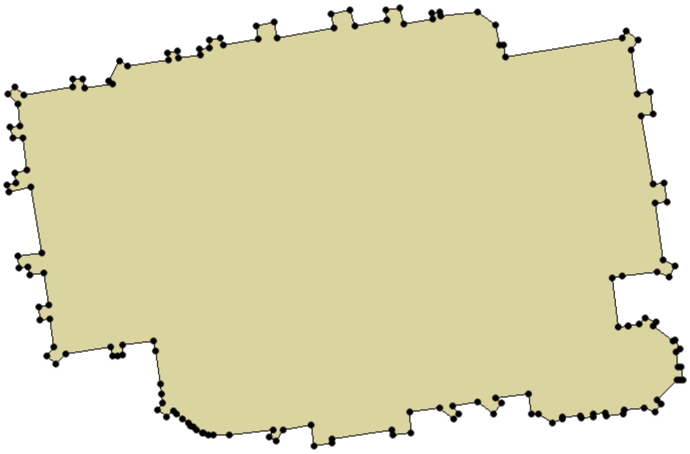


Figure 7.11: The calculation of the variable measuring shape complexity for St Giles Cathedral

7.12.2 Roads and Paths

The ***Shape Complexity*** calculation for roads and paths is the same as it is for buildings. The number of vertices on the line representing the road or path is calculated (Figure 7.12). This acts as an approximation of the straightness of a road.

From the experiments if was noted that some roads were ‘curvy’, ‘curved’, or ‘bend around’. The number of vertices ranged from 2 to 150 for the roads and paths features. If a road had two vertices it was deemed to be straight, with more vertices deeming a road feature to be more complex. Each of the variables related to shape saliency is stored as its numeric value (Table 7.9).

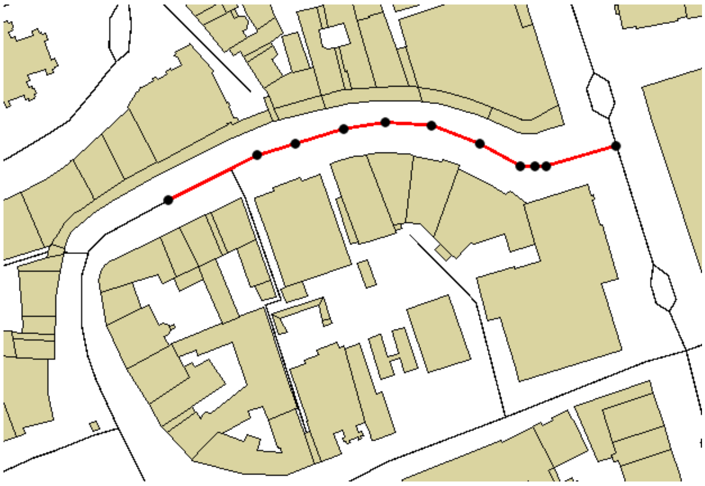


Figure 7.12: The calculation of the variable measuring shape complexity for Victoria Street

Value	**Definition**	**Features**
Shape Deviation		
Percent	Percentage of shape deviation	Buildings
Shape Complexity		
Numeric Value	Number of vertices	Buildings Roads and Paths

Table 7.9: Shape saliency variable classification

7.13 Condition Saliency

The condition saliency category is a highly subjective variable. One individual may find a feature ‘dirty’ or ‘shiny’, whilst another may have a different opinion. For example, the Scott Monument is very black in colour due to issues associated with the cleaning of the stone. As a result, some people may feel that the monument is very dirty, whilst other feel that it is a part of the feature related to its age and adds to its ‘charm’, and thus do not feel that it reflects its condition. For this reason, within the pedestrian navigation system, the condition of a feature was not modelled or measured.

The condition of features was mentioned primarily in relation to buildings, however, they were also mentioned in terms of the presence of potholes on the roads. The condition of a feature having an effect on its saliency was noted by Raubal and Winter (2002) who stated that the condition of a building often related to its age and cleanliness. Therefore, whilst it is very hard to develop a variable to reflect the condition of the building, an age variable has already been incorporated. Using the age of a building it could be assumed that features that are older are in a worse condition than those that were built more recently. This, however, may be somewhat presumptuous for a historic city such as Edinburgh. Many of the older building within Edinburgh are still in a very good condition and are well maintained.

As within the Emotions towards Features saliency category, this is a variable that could be created through the use of user participation. Individuals could interact with the pedestrian navigation system to give reports on the condition of the various features of interest that it includes and a consensus could be formed on the condition of features from this information. This consensus would fluctuate as more opinions were gathered.

7.14 Cultural and Historical Saliency

The cultural and historical significance categories have been combined as there is significant overlap between the variables created to measure their saliency. The cultural and historical saliency measure was included within Raubal and Winter’s (2002) model of saliency and was calculated as a true/false; true if a building had cultural or historical significance and false if it was not. They also speculated that this boolean value could be extended to a 1-5 scale based measure. It has been noted that the methods used for the assigning of these measures often relate to data that has been collected for the purpose of evaluating whether features required protection (Nothegger *et al.*, 2004). Within this research several of these types of datasets are used; Listed Buildings, Scheduled Ancient Monuments, and World Heritage Sites. This data provides a way of identifying those features that are of significance to protect at a variety of scales; from international to local importance. This data is then combined with the Gazetteer for Scotland and PointX's National Points of Interest to provide an overall view of the cultural and historical saliency of a feature. A limitation of this approach, however, is that there is no automatic way of extracting features which have a local cultural significance, in terms of local folklore, legend, or vernacular names. This does not affect Edinburgh to the same extent that it may affect other urban environments as Edinburgh has a more obvious visual and mappable set of cultural assets due to its rich history.

7.14.1 All Feature Types

The development of the following saliency variables can be achieved for all the features, regardless of their type. Five variables are calculated to represent cultural and historical significance:

1. World Heritage Importance
2. Scheduled Monument Importance
3. Listed Building Importance
4. Tourist Attraction
5. Historical and Cultural Attraction

World Heritage Importance illustrates whether or not a features falls within a World Heritage Site. UNESCO World Heritage Sites protect places that are of special cultural or physical significance and the Old and New Towns of Edinburgh have been assigned this protection. The inclusion of World Heritage as a measure can be attributed to the reasons behind why Edinburgh was granted this protection; "the harmonious juxtaposition of two contrasting historic areas, each with many important buildings, is what gives the city its unique character" (United Nations Educational

Scientific and Cultural Organisation (UNESCO), 2012). Features that fall within the World Heritage boundary are assigned the value of one, whilst those outside are assigned a zero (Table 7.10).

Scheduled Monument Importance reflects whether a feature lies within the boundary of a Scheduled Monument. Scheduled Monuments are monuments that have been deemed to be of national importance and are viewed to be part of both a local and national identity. Additionally, Historic Scotland (2012d) state that the monuments contribute to the history, tourism, placemaking, and local distinctiveness of Scotland. The inclusion of this variable is due to the important role that such features play within Scotland. There are only 35 Scheduled Monuments within the study area, with the major two being Edinburgh Castle and Holyrood Abbey, Palace, Garden and Park. Features that fall within a Scheduled Monument are assigned the value of one, whilst those outside are assigned a zero (Table 7.10).

Listed Building Importance measures whether a feature is listed by Historic Scotland. Features can be listed if they are of historical interest, and they are given a rating reflecting the scale of importance (national, regional, or local). This variable is only calculated for buildings and statues and monuments features types. It could also be calculated for the bridges and street furniture feature categories. A building is assigned a value of either one, two, or three based on the listed category if a listed building point is within the footprint of a building (Table 7.10). For statues and monuments there is a common unique identifier for RCAHMS and Historic Scotland data. This means that a statue or monument feature is assigned a one if their unique identifier exists within the Listed Building dataset.

Tourist Attraction reflects whether a feature is regarded as a tourist attraction. This is calculated using two datasets: PointX's National Points of Interest and the Gazetteer for Scotland. Within the Point of Interest data is a classification for tourism. This comes under the Attractions classification. Within this category there are seven sub categories including theme and adventure parks, laseria, observatories and planetaria, and siteseeing, tours, viewing and visitor centres (PointX, 2012a).

This classification can be used to classify a building feature as a tourist attraction. This information can be linked back to the building features through the use of the unique identifier (TOID) that exists between the MasterMap and PointX data. Within the study area 37 buildings are deemed to be tourist attractions and these buildings are assigned the value of one (Table 7.10). The second method of determining a tourist attraction is through the utilisation of the data in the Gazetteer for Scotland. Within this dataset, features have been classified with a tourist rating ranging from one to four stars, with only seven features being rated four stars. These included Edinburgh Castle, The Royal Mile, and St Giles Cathedral. In total there are 208 features classified as tourist attractions within the Gazetteer. All feature types may be covered by the data in the Gazetteer for Scotland. Polygon features, such as buildings and green spaces, are classified as a tourist attraction if a Gazetteer feature falls within its footprints. For feature types such as roads and paths and statues and monuments, Gazetteer points are pre-selected based on their appropriate classification (monuments category for statues and monuments features) and are then intersected with a five metre buffer with the features. This ensures that the features are assigned their correct values. This could be expanded to use information and ratings from the Scottish Tourist Board, who officially grant ratings to tourist attractions, or from downloading ratings from travel websites such as Trip Advisor, that have a function that allows the public to assign a rating.

Historical and Cultural Attraction reflects whether a feature is regarded as a historical and cultural attraction. PointX's National Points of Interest includes a classification for historical and cultural attractions. Within this category there are seven sub categories including historic buildings, art galleries, and archaeological sites (PointX, 2012a). This classification can be used to classify a building feature as a tourist attraction. This information can be linked back to the building features through the use of the unique identifier (TOID) that exists between the MasterMap and PointX data. Statues and monuments and green spaces are the other feature types where this data is appropriate for the creation of this variable. Within the study area there are 89 buildings features that can be classified as a historical and cultural attraction and these buildings are assigned the value of one (Table 7.10).

Value	Definition	Features
World Heritage Importance		
0	False	All Features
1	True	
Scheduled Monument Importance		
0	False	All Features
1	True	
Listed Building Importance		
0	Not a Listed Building	Building, Statues and Monuments, Bridges, Street Furniture
1	Listed Building - Category C(S)	
2	Listed Building - Category B	
3	Listed Building - Category A	
Tourist Attraction		
0	No	All Features
1	Yes	
Historical and Cultural Attraction		
0	No	Building, Statues and Monuments, Green Spaces
1	Yes	

Table 7.10: Cultural and historical saliency variables classification

7.15 Temporality Saliency

Temporality of a feature received a large number of references which were generally related to construction sites and road works, however, could also other features including statues and monuments and street furniture. The temporality of a feature is important for saliency as features that are only there for a short period of time stand out in comparison to those that are there permanently. There is something new and different within the everyday landscape.

The classification of the temporality variable is as follows; features were assigned a one if the features was identified as being temporary and a zero if it was permanent (Table 7.11). This reflects a higher value being on the values that are determined to be more salient, in this case the feature being temporary in the environment.

Value	Definition	Features
0	Permanent	Buildings Roads & Paths
1	Temporary	Buildings Roads & Paths

Table 7.11: Temporality saliency variable classification

7.16 Summary

There is a wide variety in the ways that the saliency categories identified in Chapter 4 and 5 could be measured using the pre-existing datasets identified in Chapter 6. A number of these variables have been previously discussed within the literature and in a few cases attempts have been made to extract such variables automatically from datasets. Such efforts, however, have primarily focused on buildings, with little discussion of other classes of features. This chapter has discussed the ways in which the different variables have been created and measured not only for buildings, but also for roads and paths and statues and monument (Table 7.12). This, however, is not a definitive list of variables but rather a list of preferred measures based on the findings of the experiments discussed in Chapters 4 and 5.

As stated, there are some variables that are problematic to generate and discussions have been presented on possible methods, such as crowd sourcing, to calculate these in the future. These variables generally relate to the more subjective categories such as conditions, emotions towards feature, and colour.

Saliency Category	Variable Name	Buildings	Roads and Paths	Statues and Monuments
Name	Name	0,2	0,2	0,2
Size	Area	Numeric	Numeric	Numeric
	Height	Numeric	-	Numeric
	Façade Area	Numeric	-	-
	Volume	Numeric	-	-
	Length	-	Numeric	-
	Width	-	Numeric	-
Age	Old	0,1	-	0,1
	New	0,1	-	0,1
Signage	Signage	0,1,2,3	-	-
Location	Location to a Street	0,1,2	-	0,1,2
	Location to a Decision Point	0,1,2	-	0,1,2
	Building Stands Alone	0.1	-	-
Architectural	Architectural Importance	0,1,2,3	-	-
Function	Function	0,1,2,3,4	-	-
Shape	Deviation	Percent	Percent	-
	Complexity	Numeric	Numeric	-
Cultural & Historical	World Heritage	0,1	0,1	0,1
	Scheduled Monuments	0,1	0,1	0,1
	Listed Buildings	0,1,2,3	-	0,1,2,3
	Tourist Attraction	0,1	-	0,1
	Historical Attraction	0,1	-	0,1
Temporary	Temporary	0,1	0,1	-

Table 7.12: Summary of saliency variables, by category and feature type

The next chapter discusses the development of the pedestrian navigation system, which includes describing how the overall saliency of a feature is calculated based on the measures identified in this chapter, how the most salient feature is selected, and how the route descriptions are generated.

Chapter 8

Development of the Pedestrian Navigation System

Chapter 7 discussed the identification, and calculation of saliency, for features of interest from the pre-existing datasets identified in Chapter 6. This chapter brings together the data, software, and saliency measure components discussed in Chapters 6 and 7, to develop the pedestrian navigation system. It starts with an introduction to the visibility analysis used in the system and then outlines how the saliency variables, calculated in Chapter 7, are used to create an overall measure of saliency. The second half of the chapter discusses the system in detail - how it is constructed, how the saliency and visibility is incorporated, how the route is generated, and how the directions are automatically generated.

8.1 Feature Visibility Analysis

The relative visibility of features is very important when it comes to determining salient features, and developing route directions. Burnett (2001) and Raubal and Winter (2002) all included visibility as a measure of saliency within their models. For Burnett this measured whether a feature was visible in all conditions, whilst Raubal and Winter measured the area that was visible from the façade of a landmark. Winter (2003) extended this work to incorporate a measure of advance visibility of façades into the overall saliency of a feature. Winter calculated advance visibility as the combination of two measures; route coverage (how much of the route is covered by the area visible from the features façade) and orientation of the feature to the heading. This advanced visibility measure is combined with the saliency measures to aid in the selection of the most salient landmark. This work, however, focussed on two-dimensional visibility which was calculated from the point of view of the landmark rather than from the point of view of the navigator. It is, therefore, important that the field of view of the navigator is taken into account alongside a three-dimensional representation of the urban environment as this can have a large effect on the visibility of features to the navigator. Brenner and Elias (2003) used a DSM to track the visibility of features every two metres along a route, to identify those features that are most visible along the route. This is very computationally intensive and is related directly to the route which has been requested. It would be extremely hard to compute this information in an efficient manner to deliver as a live interactive system.

Visibility has often been included as a measure of saliency, however, within this work it is argued that the visibility of a feature is separate from the saliency of a feature. Visibility is more importantly used to determine which features are visible when traversing a route. It was interpreted from the three experiments that the most salient feature depends on the approach to a decision point and its associated field of view. Whilst a feature may be in the field of view and the most salient approaching a decision point, it might not be when approaching the same decision point from a different direction. It is, therefore, argued that including a visibility measure of saliency using a single value to represent it does not take into account this varying degree of visibility of a feature of interest.

This research incorporates the idea of *relative visibility* to determine which features of interest are in the navigator's field of view as they approach the decision point. An individual navigating their way through an urban environment feels more comfortable the earlier they can identity their next re-orientation point (Winter, 2003). Based on these two points, the relative visibility is calculated from an observation node (a point 30 metres from the decision point) with the field of view (viewshed) focussing towards the decision point (Figure 8.1). The decision to situate the observation point 30 metres in advance of the decision point was an arbitrary distance based on the requirements of a user approaching a junction with no prior knowledge of the decision that would need to be made, so that they could be primed to make judgements on the surrounding environment in order to complete the action required. In reality, the distance of an observation point from a decision point would depend on the method by which instructions were delivered to the user and the relative speed at which they were approaching the decision point.

Figure 8.1: Illustration of an observation node, at the decision point of Princes Street and North Bridge

8.1.1 Creating Visibility Polygons

This section discusses the creation of visibility polygons that were used within the pedestrian navigation system. Each road or path that intersects a decision point has an observation node created on the network 30 metres prior to the decision point itself (Figure 8.1). Observation nodes are attributed with the unique id for both the road (or path) it lies on, and the decision point it is observing. Each observation node is attributed with the following four attributes for use within the viewshed functionality available in ArcGIS and illustrated in Figure 8.2.

OFFSETA represents the height of the observer. The average height of males and females in the United Kingdom is 1.7 and 1.6 metres respectively (Gray & Leyland, 2009). The offset height is set to the 1.6 metres as this is the lower value, accounting for the average height of both males and females.

AZIMUTH1 and *AZIMUTH2* specify the horizontal angle limits to the viewshed calculations (ESRI, 2012b). As the observation nodes are situated to view a particular decision point, these attributes are used to limit the field of view to focus in the direction of the decision point. The azimuth values are specified in degrees from north. To calculate these two values, first the angle of the line between the observation node and a decision point is determined. For AZIMUTH1, 90 degrees is subtracted from the angle of the line whilst for AZIMUTH2, 90 degrees is added to the angle of the line. This limits the search to the 180 degrees in front of the navigator. This is a wider than a person's field of vision, however, it was determined that this would allow for features that are to the immediate left or right of the participant to be included within the selection.

RADIUS2 represents the maximum distance from an observation node for which a viewshed is calculated (ESRI, 2012b). Within this analysis, this is set nominally to be 100 metres, in order to allow the user to pick out detail on a landmark if required – for example, reading signage. The search radius for the viewshed is limited as it will force a local feature to be used within the directions rather than a global landmark. This work, therefore, does not take into account of the role of global landmarks within route description. Instead it focuses on the use of local landmarks, which are of much higher importance when it comes to successfully navigating through an urban environment (Lynch, 1960). The value of 100 metres was applied to reduce the likelihood of global landmarks being included within the route descriptions. This was due to the focus of the research being on the local landmarks that are required to navigate successfully in the immediate vicinity. The 100 metre value was based on the findings of *Experiment Two* where participants were observed to only be looking within a limited distance when identifying features of interest for including within directions. The participants only started to identify features when they could see the decision point and the turn to be made and when they were within a short distance of it. This was reflected in this research using 100 metre limit, however, this value may need to be adjusted depending on the environment in which the method is being applied.

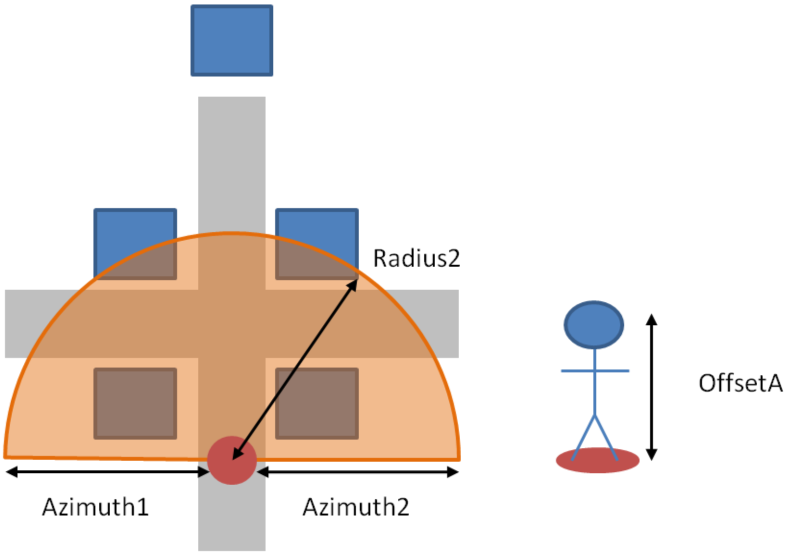


Figure 8.2: Illustration of the attributes used within the viewshed analysis

For each observation node, a viewshed is calculated using the digital elevation model (Section 6.2.5). The viewshed is then converted to a polygon representing the visible areas (*visibility polygons*) and attributed with the observation node unique identifier (Figure 8.3). The analysis was automated and completed through the development of a model within ArcGIS's ModelBuilder. ModelBuilder is a powerful tool which allows for the editing, creation, and management of models in order to automate the data manipulation process (ESRI, 2012a). The resulting visibility polygons were merged into one dataset and loaded into the pedestrian navigation system's PostgreSQL/PostGIS database. The visibility polygons are used within the next section to help determine which is the most salient feature of interest to use at each decision point.

Figure 8.3: Illustration of a visibility polygon, at the decision point of Princes Street and North Bridge

8.2 Overall Saliency of a Feature of Interest

An important step in the automatic creation of natural route description is the calculation of the overall saliency of a feature of interest. This overall saliency value directly influences which feature is selected at each decision point. Previous research has shown that there are primarily two methods used to calculate the most salient feature; mathematical modelling of saliency and clustering of landmarks to identify outliers. Raubal and Winter (2002) developed a mathematical model to measure the saliency of a landmark within the local neighbourhood. Each continuous variable was tested for its significance against the median and standard deviation for the local area. If the value was significant the variable was assigned a significance value of one, otherwise it was assigned the value of zero. The significance values were averaged for the three saliency attraction measures (visual, semantic, and structural) and then added to create an overall saliency rating. Raubal and Winter did not specify the extent of their local neighbourhood within the research, state the significance level which was applied to the results, or specify how they calculated significance for discrete data.

The other method used to calculate saliency is to apply clustering techniques. A hierarchical clustering approach was used by Elias (2003a, 2003b) to determine which buildings were potential landmarks. Clustering results in objects that are similar being grouped together whilst unique salient objects stand out, thus becoming potential landmarks. The idea behind this technique is that those features that do not fit into a cluster are spatial outliers. This research informed the work of Lazem and Sheta (2005) who developed a spatial outlier detection algorithm which identified the most salient buildings by analysing the five variables (height, colour, importance, width, and location) to find buildings with values that significantly different from their spatial neighbours.

One of the most important factors in identifying the most salient feature is that it must stand out from its surroundings and whilst previous research has calculated saliency for a local area, no one has previously taken into account what can actually be viewed in the local area as a decision point is approached. This research argues that when it comes to developing a measure of saliency, it is much more important to calculate it using those features that are within the navigator's actual field of view, rather than taking into account all the features that surround it, using a nominal measure of distance or neighbourhood. The use of visibility at decision points is an important aspect of the approach used within this thesis. This method ensures that the feature of interest that is included in the directions at the decision point is visible to the user as they approach the turn. When deciding on which feature of interest to use at a decision point, it is amongst the features that can be viewed that the distinguishing salient feature needs to be extracted. For example, if a nominal distance measure of 100 metres was used when calculating the saliency of the Balmoral Hotel in Edinburgh it would include approximately 35 other buildings, including Waverley Station, Princes Street Mall, and Register House, within the calculation (Figure 8.4).

Figure 8.4: The buildings included in the surrounding area specified by a nominal distance (100m)

However, not all of these buildings can be viewed from a single decision point; some buildings cannot be seen from any decision point because they are hidden behind other buildings. Therefore, this does not accurately reflect what an individual sees in the environment and does not specifically help the individual distinguish between those features they can view to enable successful navigation. For these reasons, this research, utilises the visibility polygons to help determine the most salient feature for each decision point based on the navigator's direction of travel (which is represented by the observation nodes and visibility polygons) (Figure 8.5 and 8.6).

Figure 8.5: The buildings included in the surrounding area specified by a visibility polygon

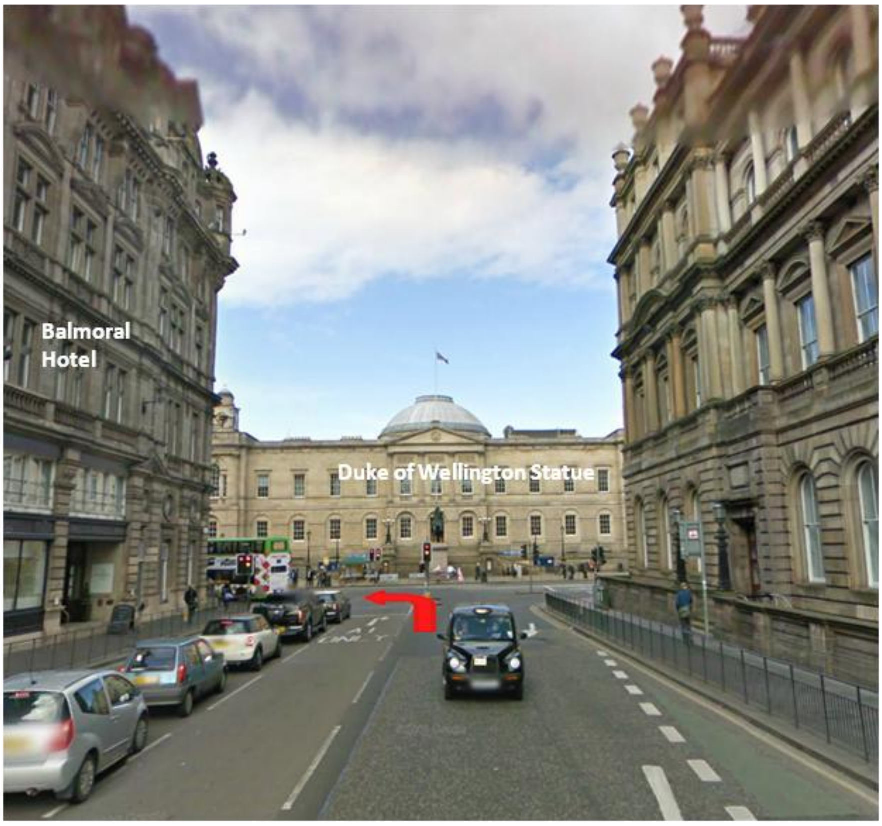


Figure 8.6: The actual field of view from the observation point in Figure 8.5 (Google Maps, 2012a)

8.2.1 Calculating Overall Saliency

To calculate the overall saliency of a feature, a method is used similar to the one introduced by Raubal and Winter (2002). Within this thesis, the saliency needs to be calculated amongst features of the same type (i.e. building, road, statue). The saliency value needs to be standardised before the saliency of different feature types can be compared and a decision made as to the most salient feature of interest to use within the route directions.

The most salient feature is calculated for every observation node. The observation node is linked to a visibility polygon, representing the field of view that the navigator would have when approaching the decision point from the observation point. For each feature type, the visibility polygon is intersected with its corresponding dataset to retrieve the features that are visible. The average and standard deviation is then calculated for these intersecting features, for each of the saliency variables measured (Table 8.1).

Using the average and standard deviation for the area, an 80 percent confidence interval is calculated. This confidence interval represents the range that the true mean of the value would be expected to lie in. Therefore, if the value for the features is greater than the higher value in the identified confidence interval, it is marked as being significant and assigned a value of one. If it is not significant, it is assigned a value of zero (Table 8.1). The average saliency for each category is then calculated.

Saliency Category	Variable Name	Balmoral Hotel	Avg for Viewshed	Significance	Avg Saliency for Category
Name	Name	2	1.33	0	0
Size	Area	3073 m^2	3457 m^2	0	0.5
	Height	32.7 m	26.57 m	1	
	Façade Area	116 m	90 m	1	
	Volume	100,493 m^3	94,909 m^3	0	
Age	Old	1	1	0	0
	New	0	0	0	
Signage	Signage	2	1	1	1
Location	Location to a Street	2	1	0	0
	Location to a Decision Point	2	1.67	0	
	Building Stands Alone	1	0.67	0	
Architectural	Architectural Importance	2	2.67	0	0
Function	Function	2	1.33	0	0
Shape	Deviation	0.05	0.11	0	0
	Complexity	67	69	0	
Cultural & Historical	World Heritage	1	1	0	0
	Scheduled Monuments	0	0	0	
	Listed Buildings	2	2.67	0	
	Tourist Attraction	0	0.33	0	
	Historical Attraction	0	0	0	
Temporary	Temporary	0	0	0	0

Table 8.1: Example calculation of the saliency of the Balmoral Hotel (Part 1)

In previous research, the concept of weighting the different saliency categories has been raised (Lazem & Sheta, 2005; Sorrows & Hirtle, 1999), although these have all worked with the assumption that each category contributes equally to the saliency of a feature (Sadeghian & Kantardzic, 2008). This is a simplistic view. The experiments conducted as part of this research have shown that some saliency categories are much more important than others, for example, the size of a feature was much more important than its shape. Weightings have, therefore, been introduced based on the percentage of each saliency category mentioned within

Experiment One (Table 8.2). The weightings have been calculated for each feature type based on the features related saliency categories.

Saliency Category	Percent of References	Buildings	Roads and Paths	Statues and Monuments
Name	33.6	0.42	0.64	0.54
Size	11.7	0.15	0.22	0.19
Age	9.6	0.12		0.16
Decoration and Signage	5.6	0.07		
Relative Location	4.7	0.06		0.08
Architecture	3.6	0.05		
Function	3.6	0.05		
Shape	3.5	0.04	0.07	
Cultural and Historical Significance	2.2	0.03	0.04	0.04
Temporality	1.4	0.02	0.03	

Table 8.2: Weightings for the saliency categories, by feature type

Finally, this weighting value is applied to the average saliency for each category, to generate the applied weighting for each category (Table 8.3). The applied weighting column is combined to provide an overall saliency value.

Saliency Category	Avg Saliency for Category	Weighting	Applied Weighting
Name	0	0.42	0
Size	0.5	0.15	0.075
Age	0	0.12	0
Signage	1	0.07	0.07
Location	0	0.06	0
Architectural	0	0.05	0
Function	0	0.05	0
Shape	0	0.04	0
Cultural & Historical	0	0.03	0
Temporary	0	0.02	0
Overall Saliency			**0.145**

Table 8.3: Example calculation of the saliency of the Balmoral Hotel (Part 2)

If there is only one feature of a type in the viewshed, as may be the case with statues and monuments, the saliency is calculated by stating that all the saliency variables are significant, unless it has the value of zero. The calculation of the overall saliency value for the Duke of Wellington statue is shown in Tables 8.4 and 8.5 below.

Saliency Category	**Variable Name**	**Duke of Wellington Statue**	**Significance**	**Avg Saliency for Category**
Name	Name	2	1	1
Size	Area	11.7 m^2	1	1
	Height		1	
Age	Old	1	1	0.5
	New	0	0	
Location	Location to a Street	1	1	1
	Location to a Decision Point	1	1	
Cultural & Historical	World Heritage	1	1	0.6
	Scheduled Monuments	0	0	
	Listed Buildings	1	1	
	Tourist Attraction	0	0	
	Historical Attraction	1	1	

Table 8.4: Example calculation of the saliency of the Duke of Wellington Statue (Part 1)

Saliency Category	**Avg Saliency for Category**	**Weighting**	**Applied Weighting**
Name	1	0.54	0.54
Size	1	0.19	0.19
Age	0.5	0.16	0.08
Location	1	0.08	0.08
Cultural & Historical	0.6	0.04	0.024
Overall Saliency			**0.914**

Table 8.5: Example calculation of the saliency of the Duke of Wellington Statue (Part 2)

The overall saliency of each feature within a visibility polygon is pre-calculated as calculating this within a live system would be extremely slow. The most salient feature of each type is then attributed to the observation node along with its overall saliency value. These salient features are then accessed by the pedestrian navigation system, which compares the three saliency values and decides which is the most salient to use at the decision point.

The example calculations above, are for the overall saliency for the Balmoral Hotel and the Duke of Wellington's statue which both lie on the intersection of North Bridge with Princes Street and Waterloo Place (Figure 8.6). The observation node that saliency was being calculated for was 30 metres from the intersection on North Bridge. The Balmoral Hotel has been calculated as the most salient building feature with a value of 0.145, whilst the Duke of Wellington's statue is the only monument in the viewshed and its calculated saliency as 0.914. In this case the statue has the highest overall saliency and is selected to be used as the feature of interest for this observation node.

8.3 The Pedestrian Navigation System

The aim of the pedestrian navigation system is to provide an efficient method of providing route directions which are suitable for pedestrians and incorporate references to the salient features of interest along the route, in order to aid successful navigation. As described in Chapter 6, the technology used to develop the pedestrian navigation system is primarily open-sourced and includes PostgreSQL, PostGIS, pgRouting, MapServer, and OpenLayers.

All the datasets required for the system are stored within a PostgreSQL/PostGIS database. This data includes:

- The features of interest datasets (buildings, roads and paths, and statues and monuments) with their associated saliency variables and measures;
- The routing network;
- The observation nodes;
- The visibility polygons.

It is important for all of the data to be pre-computed and stored within the database. This is because the system would not be able to operate in real time if the computation was required. This also ensures that when a route is requested from the system, the route, salient features, and descriptions are returned efficiently to the user. Car navigation systems are also traditionally developed using pre-computed databases (Brenner & Elias, 2003).

The pedestrian navigation system is presented to the user through a web based interface (Figure 8.7). This is a proof of concept interface and would be refined for a production system which would work both on a computer and a mobile device. An interactive map is available to the user on which they can locate the start and end locations for the route, view both the route and the salient features of interest. The background mapping is Ordnance Survey Street View.

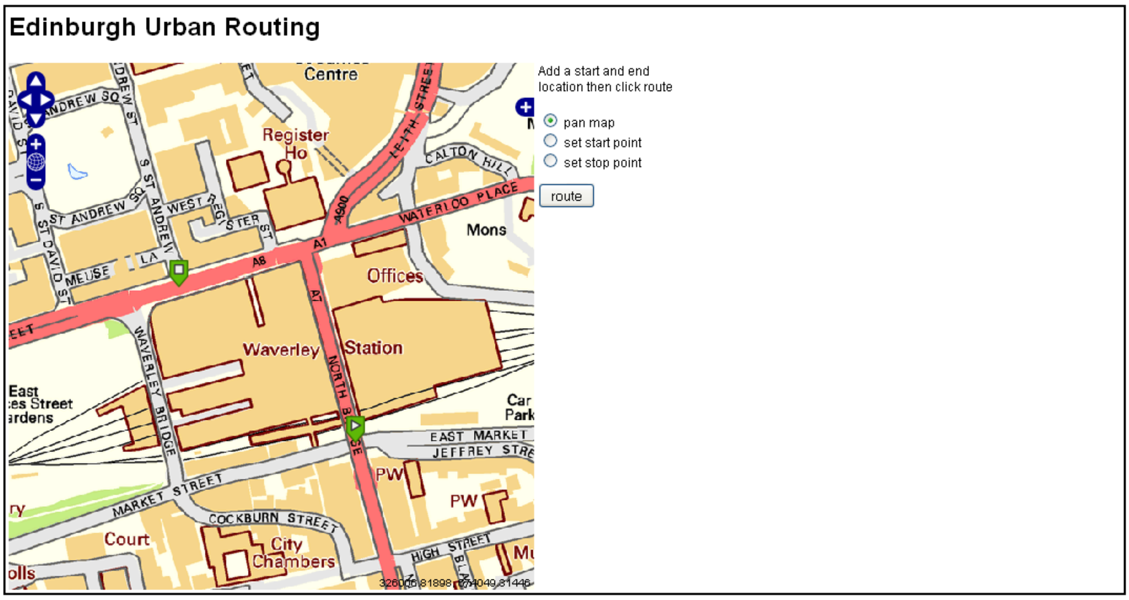


Figure 8.7: The pedestrian navigation system interface

To use the system, a user locates the origin ('start') and destination ('end') points for the route they wish to travel on the map and clicks the 'route' button. The system then returns a set of textual route directions and then the route, along with the associated features of interest, are illustrated on the map (Figure 8.8).

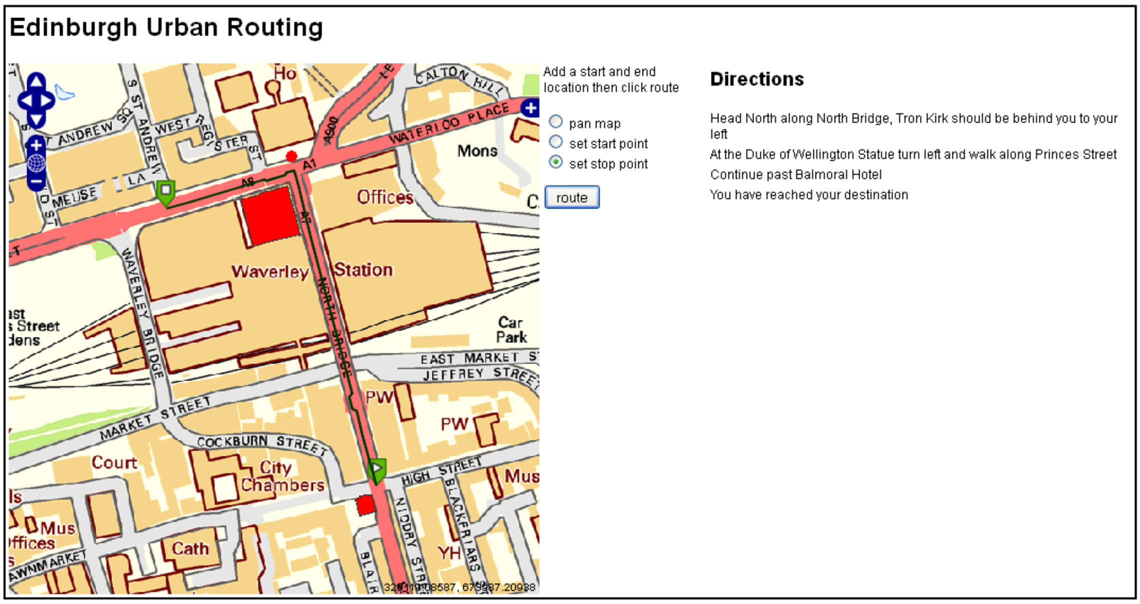


Figure 8.8: The pedestrian navigation system returning a route, features, and directions

What occurs ‘behind the scenes’ is illustrated in Figure 8.9. Once a user clicks the ‘route’ button the start and end point locations of the required route are retrieved. These locations are passed into a PHP script which interacts with the PostgreSQL/PostGIS database, using its pgRouting extension to calculate the nearest point on the routing network to the start and end location. The routing is then performed, calculating the feature-rich route (Section 8.3.2) between the points and the most salient features (Section 8.3.3) along the route are selected. The textual descriptions are then written and displayed (Section 8.3.4). The route and features of interest are returned to the webpage as GeoJSON strings. GeoJSON is a format for encoding geographic data structures used to pass geographic information between different applications, such as web pages (Butler *et al.*, 2012). It is similar to XML, however has a more compact structure and is easily parsed and displayed by OpenLayers. The two GeoJSON strings are interpreted by OpenLayers, which displays them as separate layers on the interactive map. Each of the major steps within this process is explained in more details in the following sections.

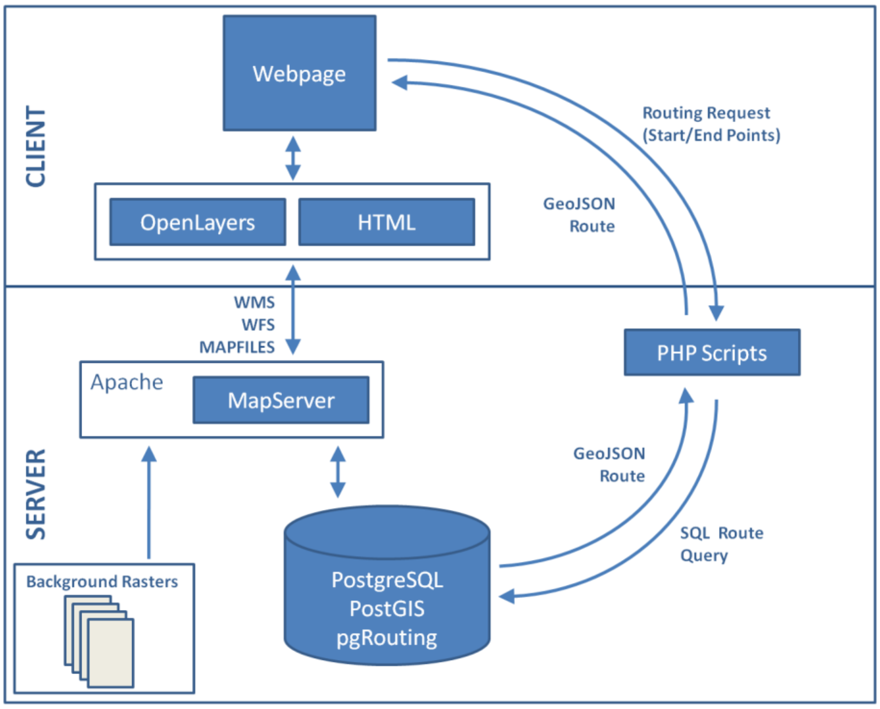


Figure 8.9: The flow of information for the pedestrian navigation system

8.3.1 The Routing Network

In order to enable effective routing, it is important to be able to accurately model the spaces which can be traversed. As the aim of this research is to create route descriptions for the pedestrian it was important to include footpath information. Ordnance Survey's ITN Urban Paths is used in conjunction with the ITN Road Network to provide a complete pedestrian routing network for the City of Edinburgh. These two datasets are created by the Ordnance Survey to be used together as a single dataset where required. The Urban Path Network includes 'path links' features which join each path to the nearest road. Processing was required to enable the two datasets to successfully work together. This involved new intersections in the ITN Road Network being created where they intersected with the Path Network. The road and path features were attributed with the name of the roads and paths where available, as discussed in Section 7.2.2. The road and path features were loaded into a PostgreSQL/PostGIS database and using pgRouting the network topology was created to permit the routing algorithm to run.

Problems exist within the ITN Road Network due to the multi-layered nature of the City of Edinburgh. A number of roads, and bridges that cross above other roads, are marked as intersecting in the data, whereas in reality they do not intersect. After the network topology was created approximately ten of these intersections (decision points) were manually removed from the data to enable a correct model to be created. These intersections were removed as otherwise they resulted in routes that could not be followed as decision points were included between roads that did not intersect. This is an issue with the use of the pgRouting software as it assumes that any two roads that cross must intersect. Therefore, more development work is required within pgRouting to allow complex multi-layer environments to be accurately represented

8.3.2 Route Selection

There are a variety of different methods which can be used for path selection within pedestrian wayfinding - from shortest distance, least time, or fewest turns, to most scenic, or straightest route (Dalton, 2003; Elias & Sester, 2006; Golledge, 1995, 1999a). Most often the simplest path to follow for navigational purposes is not necessarily the shortest path. Cognitive studies have shown that individuals will often choose the straightest possible route, as opposed to one that is more meandering (Dalton, 2003). Individuals will often use *a priori* knowledge to compress known steps and re-route through known locations (Nothegger *et al.*, 2004), sacrificing speed and completeness for conciseness and familiarity (Patel *et al.*, 2006).

A number of different algorithms have been developed to identify optimal routes. The landmark spider approach is used to suggest the clearest route. This is based on weighting each road with the saliency value of the most prominent landmark, at the upcoming decision point, in the shortest path calculation rather than using geometric distances (Caduff & Timpf, 2005). Wiener *et al.* (2004) proposed a least-decision load strategy thus reducing the number of decisions that the individual must make. Similarly, Winter (2002) presents an approach to modelling *turning cost* in a line graph. Additionally, Duckham and Kulik (2003) proposed an algorithm that can be used to select routes that minimize the complexity of instructions, based on the idea of *easing the descriptions* that was first introduced by Mark (1986). This assumes that the number and type of turns burden the route with a specific weight. However, while Mark uses a weighting function to join metric distances, Duckham and Kulik rely on a measure of instruction complexity.

Millonig and Schechtner (2005) note that pedestrian navigation services have difficulties in providing an ‘optimal’ route suggestion as human’s perception of space differs in many ways, which provokes people to develop different strategies to solve a navigational task. They suggest that individuals’ spatial behaviour is influenced by a large number of factors including age, gender, social and cultural background, as well as the physical environment through which they are navigating.

As discussed above, there is no common agreement on what constitutes an ‘optimal’ route. For the pedestrian it is important for the descriptions to be easily understood and followed for successful navigation. It has been shown through numerous experiments (Daniel & Denis, 1998, 2004; Denis *et al.*, 1999; Tom & Denis, 2004; Weissensteiner & Winter, 2004) that the inclusion of landmarks (or features of interest) within directions significantly improves that chance of successful route-finding. On this basis, this research, argues that the route created and its description should ensure that the navigator is directed through ‘landmark rich’ areas, as opposed to ‘landmark deserts’ whilst still taking the length of the route into account.

Landmark deserts are areas where there are very few features of interest that are salient within the landscape. For example, a residential street where all the houses are similar or even identical is a landmark desert. Landmark rich areas would be an abundance of features that could be used to direct a navigator. If a road is devoid of features of interest it is better for an individual to take a slightly longer route that has more features, that is easier to describe and follow, than to take a shorter route that may lead to navigation errors.

The routing algorithm used in this research is the Dijkstra shortest path algorithm (Dijkstra, 1959). Dijkstra shortest path algorithm was used, as it was the most reliable algorithm provided by pgRouting. The Dijkstra algorithm has a cost value associated to each routing link in the network. For each road, or path, the initial cost assigned is its length in metres (as per Section 7.3.2). Using this cost value would result in the shortest path between two points being returned every time the pedestrian navigation system is used. As the system was required to provide routes through landmark rich areas the initial cost value is subsequently weighted based on the number of salient features along that particular road or path. The weighting is calculated by selecting all the features of interests that are located along a road, or path, retrieving their associated saliency values and averaging them. This therefore assigns each road a value between zero and one to the roads. The higher the average saliency the more landmark-rich the road is determined to be. To calculate the overall cost value for Dijkstra algorithm the average saliency value is subtracted from one and multiplied by the length of the road, or path. This means that a road which has no salient feature of interest would be assigned a maximum weighting of one and the more features there are on the road the lower its associated cost would be. It is important to take the length of the road into account, as the route also needs to be optimised in terms of distance and time taken to traverse it.

8.3.3 Selecting the Most Salient Feature of Interest

The features of interest included within the route descriptions are selected based on the overall saliency value of the features, and the visibility polygons for each decision point of the required route. Once a route has been determined, each of the observation nodes that intersect the route (points 30 metres prior to decision points) are extracted. Each observation point is attributed with the road it is located on, and the decision point it is observing, allowing for the easy identification of the correct node.

The visibility polygon associated with this observation node is retrieved. The visibility polygon is intersected with the features of interest layers (i.e. buildings, roads and paths, and statues and monuments). From all the features that intersect the viewshed, the feature that is used within the route directions is the one with the highest saliency value.

8.3.4 Route Directions Generation

Once the route has been generated and the most salient features selected, the next step is to create the textual description of the route. It has been noted that successful route descriptions need to reflect the way individuals communicate, such as combining several separate directions steps into one sentence (Dale *et al.*, 2002; Furlan *et al.*, 2007; Hansen *et al.*, 2007). Within this thesis, the information regarding the feature of interest, the turn direction, and name of the road that is being turned onto are combined into one direction statement.

Within the experiments it was observed that both primary and confirmatory cues were referred to by the participants. In *Experiment Two*, confirmatory cues accounted for around 60 to 70 percent of the statements within the descriptions. Often they were used around possible reorientation points, where change of direction could take place but where the route actually continued straight ahead. Additionally, the vast majority of confirmatory cues used in the experiments made reference to features of interest. In this research, therefore, confirmatory cues to features of interest are included in the route directions at decision points where the route continues along the same road or path, which is determined by the name of the road, or path.

Within the experiments there was no use of the ‘you have gone too far’ cue, therefore, it was determined that these would not be included within the textual route descriptions.

The directions were generated in relation to each decision point in the route. The first road or path is written differently to the rest of the route as it is described in terms of the general compass direction to start to walk (Figure 8.10) and includes a reference to the location of the salient feature of interest at the start point. For example 'Head West up the Royal Mile, the Tron Kirk should be on your left'. This first feature of interest is selected by extracting the most salient feature within 30 metres of the decision point and calculating its relationship to the start point. For example is the feature to the left or right of the start point and is it in front or behind the start point? (Figure 8.11). The construction of the first instruction in a set of route directions is very important as it allows the navigator to locate themselves in the right place and facing the right direction before they start navigating the route. This means that the navigator is 'on the right track' from the beginning of the route. It is within these initial directions where global landmarks are of importance.

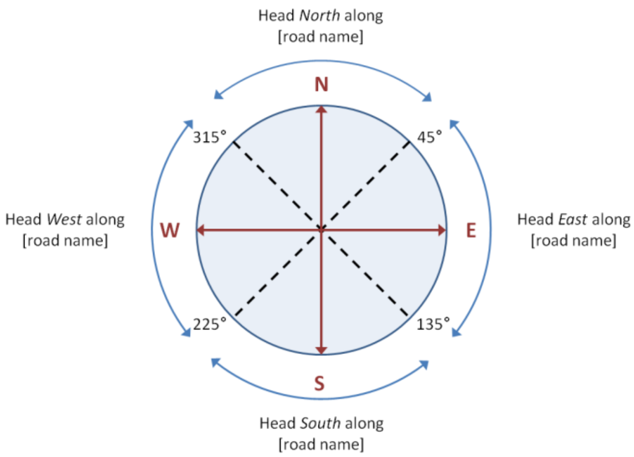


Figure 8.10: Compass direction interpretation for first statement of route directions

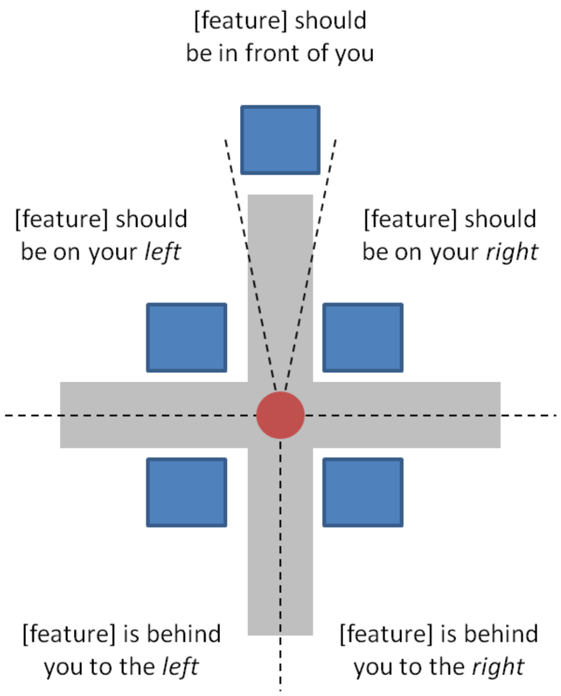


Figure 8.11: Feature of interest location interpretation for first statement of route directions

All subsequent decision points on the route are described in the same manner using the following direction statement:

At the [feature] [turn description] and walk [gradient descriptor] [road name]

"At the Balmoral Hotel turn left and walk along Princes Street"
"At the Statue of David Hume turn right and walk down Bank Street"
"At the Premier Inn turn left and walk along Lauriston Place"

Where *feature* refers to the most salient feature of interest at the decision point and *turn description* refers to a textual description of the turn required to be made. *Gradient descriptor* refers to the change in slope along the next road which is identified by the *road name*.

If a road name was detected not to have changed after a decision point, a new direction statement was not created. Rather a confirmatory cue was included in the directions specified with the following statement:

Continue past [feature]

"At the Balmoral Hotel turn left and walk along Princes Street"
"Continue past Scott Monument"

"At the Premier Inn turn left and walk along Lauriston Place"
"Continue past Edinburgh College of Art"
"Continue past George Heriot's School"

The feature of interest and road or path name is included using the name variable that was assigned when creating the saliency variables. The most salient feature is selected using the method discussed in the previous section, for both the direction statement and the confirmatory cue.

The turn description is created by determining the turn that occurs between the two roads on the route that intersect at the particular decision point. These are expressed in relation to the type of turn that is required to be made such as 'slight', 'sharp', or 'u-turn' (Figure 8.12).

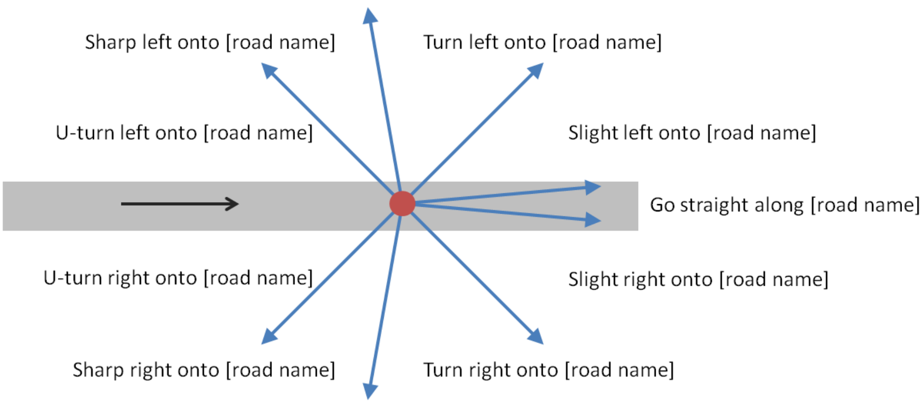


Figure 8.12: Textual direction descriptions for the turns along a route

The type of turn is determined by calculating the difference between the angle of the previous road and the angle of the next road to be traversed (Figure 8.13). This is then translated into a turn description using Table 8.6. If the difference is negative then it is a right hand turn, if it is positive it is a left hand turn.

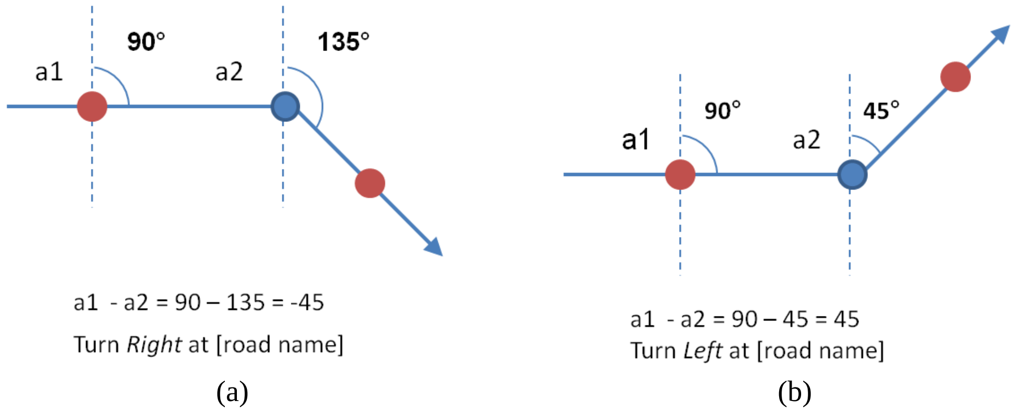


Figure 8.13: Explaining how direction of turns are calculated for a right turn (a) and a left turn (b)

Degree Difference	Textual Description for Turns
-5° to 5°	Continue straight on
-45° to -5°	Take a slight right
-100° to -45°	Turn right
-135° to -100°	Take a sharp right
-180° to -135°	Take a u-turn right
5° to 45°	Take a slight left
45° to 100°	Turn left
100° to 135°	Take a sharp left
135° to 180°	Take a u-turn left

Table 8.6: Textual descriptions for the turns along a route

It was also noted that 85 percent of the participants referred to the gradient of roads within their route descriptions, therefore, a gradient descriptor was included within the direction statement. For each of the roads and paths in the routing network, the height at the start and end of its line representation is extracted from the DSM. For each road and path a gradient descriptor is created and if the start height is more than five metres greater than the end height the gradient descriptor is set to *down*. If it is five metres less than the end height, the gradient descriptor is set to *up*, and if they are within five metres of each other the gradient descriptor is set to 'along'. When creating the description, this information is accessed for each road on the route and included in the directions, replacing the word *along* in the description with either *up* or *down*.

The pgRouting extension does not take into account the start and end point of the line feature representing the road or path. It is, therefore, necessary to reverse the direction of the line in order to generate correct descriptions (i.e. the start of the line becomes the end). If a road or path is reversed then the gradient descriptor is also reversed (i.e. ‘up’ becomes ‘down’).

Finally, the descriptions are closed with ‘you have reached your destination’.

The above discussion of textual descriptions which are triggered by visibility analysis is a good example of how this research is applicable to mobile applications of various types. For example, mobile navigation devices could vocalise these directions to make it easier for the navigator to follow the route, by keeping their hands-free and allowing them to fully focus on the environment around them and identifying the features of interest and decision points at which to turn. These systems could also allow the user to speak to the device to repeat the direction if required or to use the inbuilt GPS to provide the next direction when the navigator gets within a set distance of the turn (Bartie & Mackaness, 2006).

8.4 Summary

This chapter has discussed the method used to calculate the overall saliency of a feature and the associated visibility analysis which is applied to each decision point in order to select the feature by which to direct the user. The workings of the pedestrian navigation system have also been outlined; from selecting the route to creating textual directions.

In doing so, this chapter has brought together the results from the three experiments described in Chapter 3 and analysed in Chapters 4 and 5, with the various data sets described in Chapter 6 and associated saliency variables described in Chapter 7 in order to create a working system that returns landmark enriched route directions based on empirical evidence in an automated manner, derived entirely from pre-existing datasets. The next chapter provides an evaluation of the pedestrian navigation system, comparing routes created by the system to a set of directions gathered from the public.

Chapter 9

Evaluation of the Pedestrian Navigation System

This thesis set out to automatically generate more natural, and richer, route descriptions through the automatic incorporation of features of interest information to provide directions for pedestrian navigation. The information to be included in such route directions was determined through three field based experiments discussed in Chapters 4 and 5. The results of the experiments informed the modelling requirements for the identification of features, the saliency categories and measures, and the textual route descriptions for the development of the automated pedestrian navigation system described in Chapters 7 and 8. Implementation of the findings of the experiments therefore effectively trained the pedestrian navigation system to be able to identify the most salient features in an urban environment.

The key aspects of this system are the inclusion of salient features of interest within the directions, the use of a variety of feature types, and routing through landmark rich areas. However, it remains to be assessed how effective the pedestrian navigation system is at providing a landmark rich route, and extracting the type of features that people often include within their directions. This chapter, therefore, evaluates the pedestrian navigation system by comparing the generated output of the system - the route directions - against other existing routing systems, Google Maps and Bing Maps, and routes as described by a sample of individuals in the street, with knowledge of the study area.

The aim of this evaluation is therefore to test the output of the pedestrian navigation system in terms of both the routes generated, and the salient features identified for navigational purposes along the routes. Routing is tested through comparison with routes generated by other online systems, as well as routes generated from the 'cognitive map' as accessed by a sample of experiment participants. The salient features identified by the pedestrian navigation system for navigation are then assessed against those seen as significant for navigation to the evaluation experiment participants. This experiment is applicable as it allows for the testing of the automatically included features of interest, to investigate if they accurately reflect those features that would be extracted from the environment by individuals in the area.

Other evaluation experiments could have been conducted to include the actual 'real world' testing of the route directions generated by the pedestrian navigation system and by comparing the effectiveness of them to directions developed by other web-based systems (such as Google Maps) which do not currently include features of interest information. This experiment would have required a set of participants to individually follow either a set of directions from the pedestrian navigation system or Google Maps with the experimenter following them to record the number of times they stopped to check the directions, the length of these stops, the number of times they got lost, how long they were lost for, and how long it took to traverse the route. It was determined, however, that to effectively test the directions these participants would be required to have no prior knowledge of the study area. This is because if one were to use a participant that has a knowledge of an area, however limited, a false picture will emerge of how effective the directions are as they may already know where a decision point is, or where a feature of interest is that is included within the route. This meant that tourist or new students to Edinburgh would be required. Unfortunately the time for new students arriving to Edinburgh did not coincide with the time frame for the evaluation experiments. It was problematic to find tourists willing to take part in a test of the experiment. The study required at least 30 to 40 participants and it was found that tourists were not very willing to give up an hour or two of their holiday time to take part, even for a small payment. An additional experiment would have been to publish the pedestrian navigation system online and solicit live feedback and responses on their impressions of the system and on the directions being generated.

9.1 The Evaluation Experiment Methodology

This evaluation experiment was conducted to clarify if the conclusions drawn from the initial experiments, and thus implemented to train the pedestrian navigation system, were valid and more widely applicable than to the test routes used. The participants were chosen at random in the street and asked whether they knew how to get to the destination from the origin point in the manner that one would ask a stranger for directions to an unfamiliar destination, as per the scenario envisaged to introduce this thesis (Chapter 1, page 1). If it was confirmed that the participant knew how to get to the destination, they were then asked if they would like to provide direction as part of a piece of research. Using this approach, individuals participated only if they believed they had sufficient knowledge to provide direction – i.e. a cognitive map of the area. Those who did not feel inclined to take part, or did not have sufficient knowledge in order to provide directions, were politely thanked for their time and did not take part in the experiment.

Participants were asked to sign a consent form, and answer three questions regarding their age, familiarity with the area, and if a resident of Edinburgh, how long they had lived in the city. For the main part of the experiment, the participants were asked to provide a set of route directions to a destination point, and to assume that the description was for a person that was unfamiliar with the city of Edinburgh. The participants were given free choice of the route that they described, which resulted in descriptions of a various routes to the destination. This meant that the participants gave consideration to the directions they were giving, in terms of the route that they selected and the information they included within descriptions. The experiment prompted participants to visualise the route required from memory and describe the features that they saw as important along the route. Thus the participants were required to access their cognitive map of the area. This was important as it was not specifically the accuracy of the descriptions that was in question, rather it was the contextual information they included that was of interest. The participants were not limited in the time they were given to respond and could include as much, or as little, detail as they deemed necessary.

The output of the evaluation experiment was a set of 40 short descriptions of routes between the defined start/end locations in the centre of Edinburgh; St Andrew Square and the National Museum of Scotland, on Chambers Street (Figure 9.1). These two locations were chosen as a number of different routes could feasibly be traversed between the start and end points. This allowed for investigation of both the routes selected and the features of interest selected to augment the directions generated by the system.

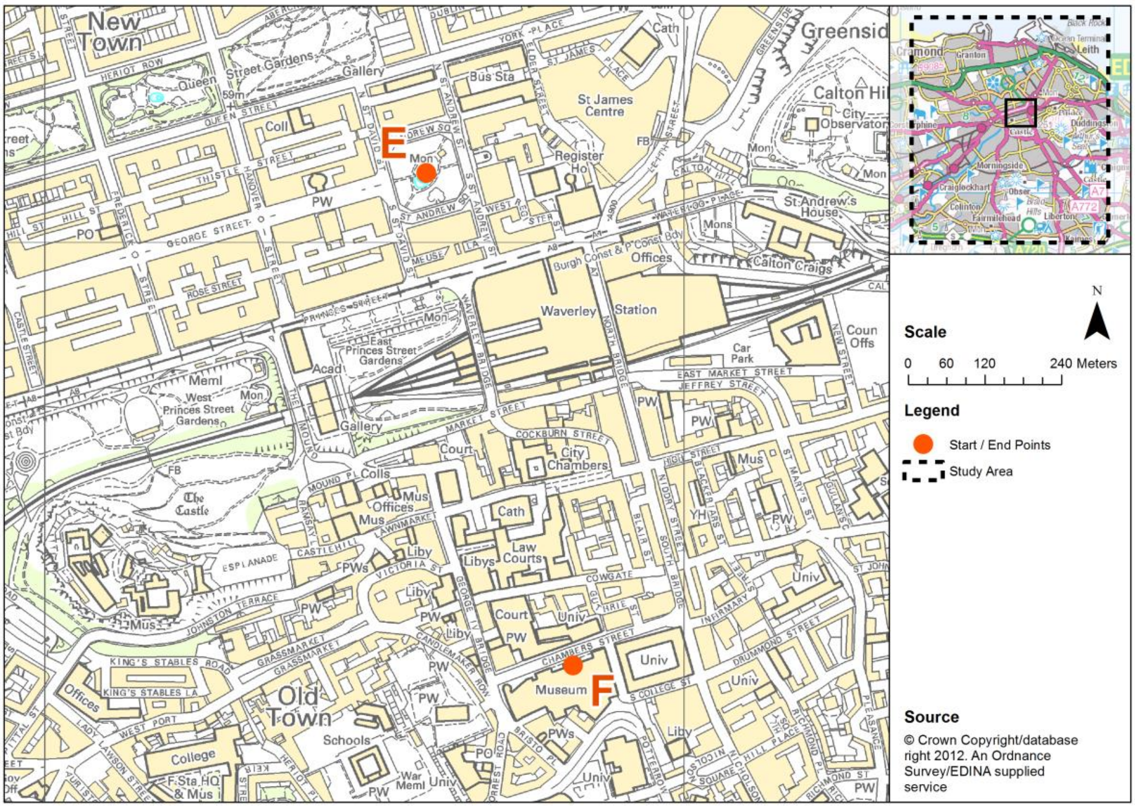


Figure 9.1: Illustration of the two start/end locations. E is St Andrew Square and F is the National Museum of Scotland

Descriptions were collected in both directions using each location as the start point, therefore allowing the investigation of how well visibility is modelled within the system, when the same route is undertaken but in the opposite direction. A pronounced change in gradient also exists between the start and end points, which provided the opportunity for gradient descriptors to be evaluated.

In total, 20 descriptions were collected from each start location; the National Museum of Scotland and St Andrew Square. Tables 9.1 and 9.2 are example transcriptions from the evaluation participants.

Directions
Go down here onto Princes Street
Turn right to go to The Mound which is next to the National Gallery I think
Then go up The Mound
Follow that up to the Royal Mile
Cross the Royal Mile
If you keep going you come to a big modern building on your left hand side
That is the Museum

Table 9.1: Example transcription for the direction E–F, St Andrew Square to the National Museum of Scotland (Participant E24)

Directions
Go down to the right here, down Chambers Street
Turn left then go over the Bridges
There's a hotel on the bottom corner, the Balmoral I think it is, it used to be the North British Hotel
You turn left there and go along Princes Street
Take the first right opposite the shopping centre, the Waverley Shopping Centre I think
St Andrew Square is there on the right

Table 9.2: Example transcription for the direction F-E, National Museum of Scotland to St Andrew Square (Participant E14)

9.2 The Participants

Of the 40 participants, 23 were female and 17 were male. The ages of the participants ranged from 20 to 85 years old, with just over a third of the participants aged between 40 to 49 years old (Figure 9.2).

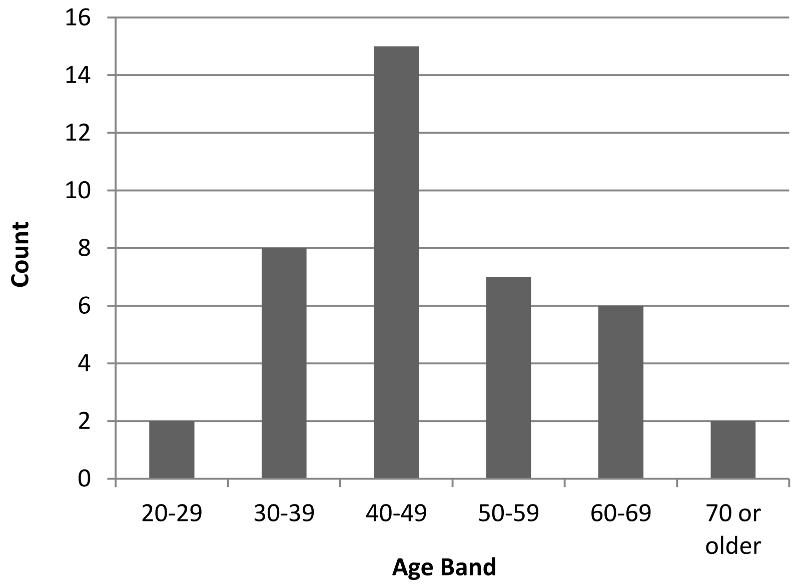


Figure 9.2: Participants' age bands

In conducting the research individuals were first asked whether they knew how to get to the destination from the origin point, therefore those asked to take part but who did not feel they were familiar enough with the area to describe the route defaulted to non-participation. This resulted in approximately 65 percent of the participants who felt that they were very or extremely familiar with the area whilst 30 percent stated that they were moderately familiar with the area (Figure 9.3). Only two participants stated that they were only slightly familiar with the area. The participants' length of residency in Edinburgh varied from zero years to 85 years. A quarter of the participants stated that they did not live in Edinburgh, but that they either worked within the area or visited Edinburgh very often. This was reflected in their stated familiarity with the area, which was either very familiar or extremely familiar.

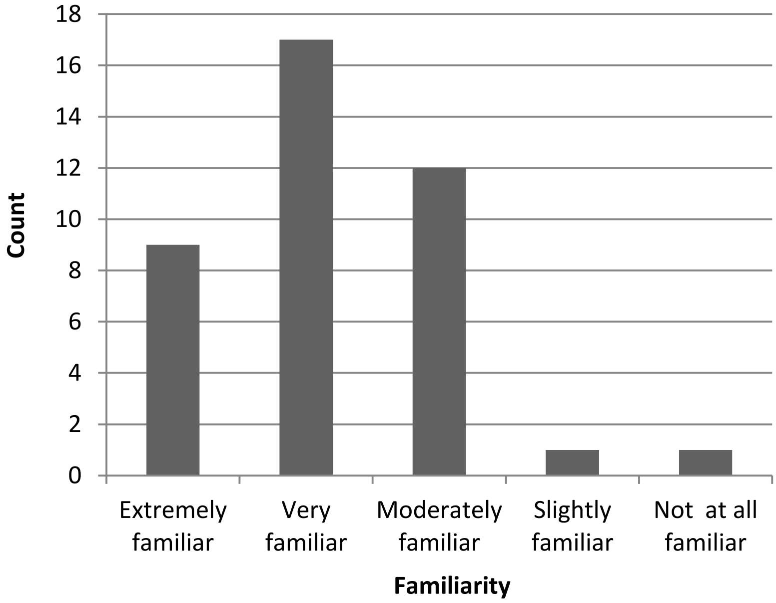


Figure 9.3: Participants' familiarity with the area

9.3 Routes

An important aspect of the development of the pedestrian navigation system was the implementation of feature-rich routing. The optimal routing was implemented based on the combination of the length of the road, or path, traversed and an assigned weighting that reflected the salient features along the road. The higher the weight the less salient features there were along the road. The pedestrian navigation system, therefore, returned route directions that would be easier to follow as they ensured that the navigator was taken through areas where there were more salient features to follow. This section discusses the comparison of the route generated by the pedestrian navigation system with those generated by online mapping systems and those identified by the evaluation experiment participants in order to explore the effect of considering salient features in route selection.

In order to provide a baseline, routes were generated using two of the most popular online routing services, provided by Google Maps and Bing Maps. The route directions generated by these systems, and presented to users, are currently composed entirely of street name information. Distinct differences were however noticeable between these systems when looking at the routes that each suggested between the evaluation experiment origin / destination points. In order to provide comparison between the systems, start and end points were placed at points E and F as illustrated in Figure 9.1 and a route between the points requested.

Google Maps selects the route that goes via George IV Bridge, the Playfair Steps, and Princes Street (Figure 9.4) whilst Bing Maps returns the route that goes via George IV Bridge, The News Steps, and Waverley Bridge (Figure 9.5).

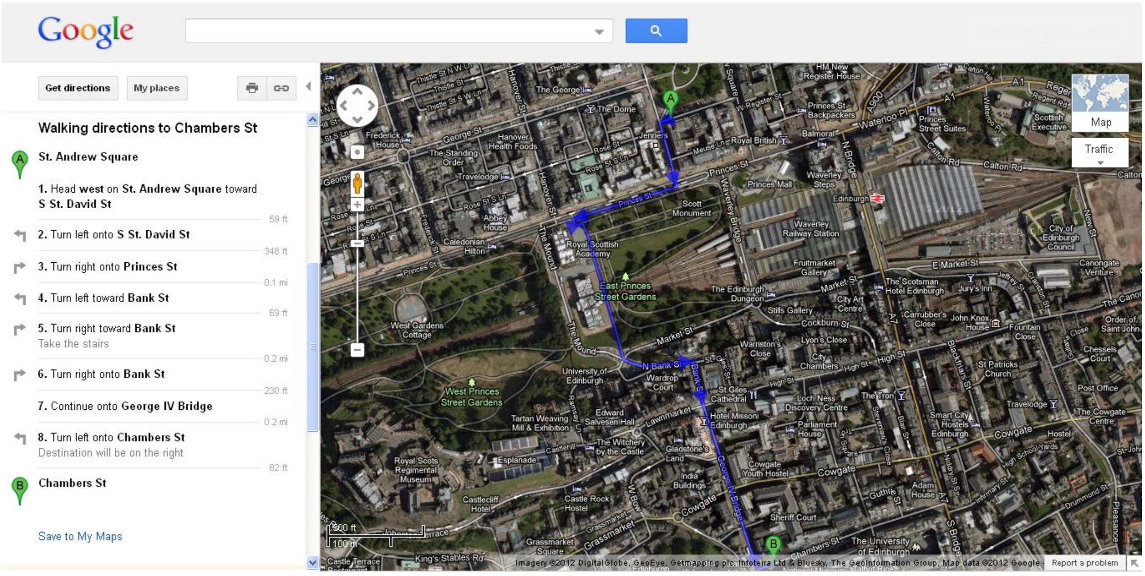


Figure 9.4: Google Map directions for Route E-F (Google Maps, 2012b)

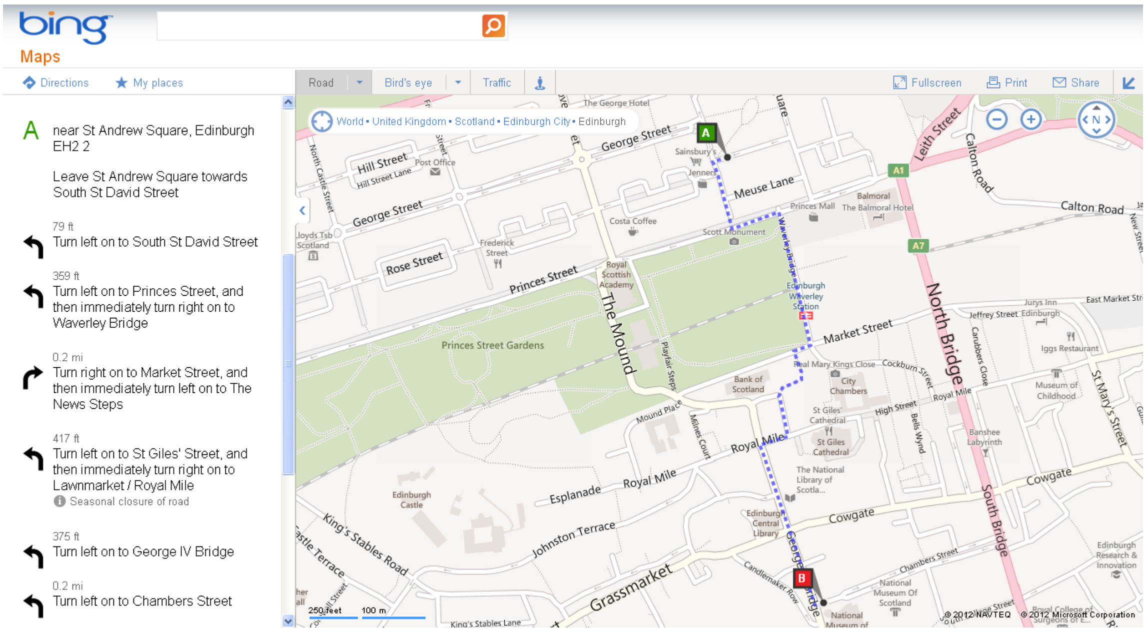


Figure 9.5: Bing Map directions for Route E-F (Bing Maps, 2012)

Bing Maps reports the shortest route possible between the two points within the full road and path network. This is the same route that is reported from the pedestrian navigation system when feature-rich routing is not implemented. This shortest route path is 935 metres (0.58 miles) in length. Within the pedestrian navigation system, this route is not however reported as the feature-rich route when taking account of salient features as there is a high weighting (i.e. a lack of features of interest) associated with the several roads along this shortest path route, including The News Steps, due to the limited availability of surrounding salient features. This route is not reported within Google Maps as The News Steps do not exist within their street network.

The route generated by the pedestrian navigation system is identical to the one suggested by Google Maps (Figure 9.6). This route uses a set of stairs (The Playfair Steps) and footpath that are much more visible and surrounded by a number of salient features, including a statue and two art galleries. Hence, these paths are assigned a low weighting due to the salient features within the surrounding area.

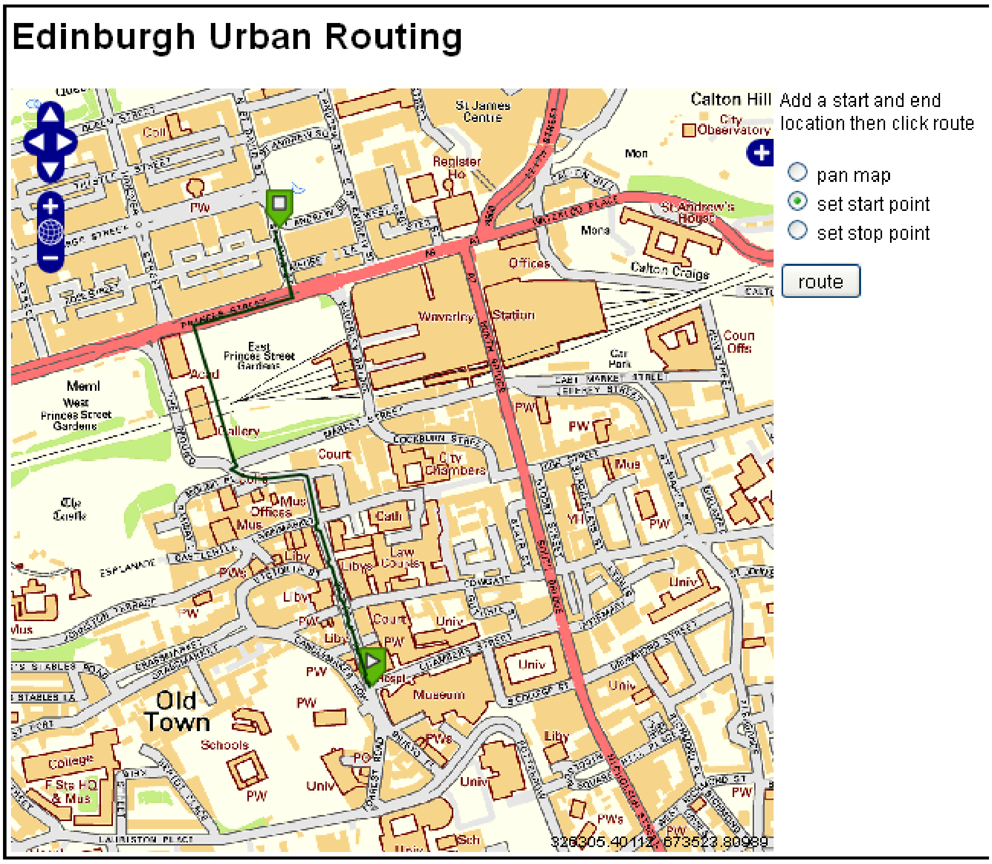


Figure 9.6. The feature-rich route returned by the pedestrian navigation system

Interestingly, when moving the location of the point to the other side of St Andrew Square or to the other end of the National Museum on Chambers Street, the suggested route changes for all three systems. This shows that the margin of difference, in terms of length, between the routes is small with four different routes being of similar overall length. Bing Maps returns a route that goes via the Old Fishmarket Close and Cockburn Street (Figure 9.7) while both Google and the pedestrian navigation system return a route via North and South Bridge (Figure 9.8 and 9.9). Again the pedestrian navigation system does not report the route via Old Fishmarket Close as it has a high weighting associated to it due to the lack of salient features.

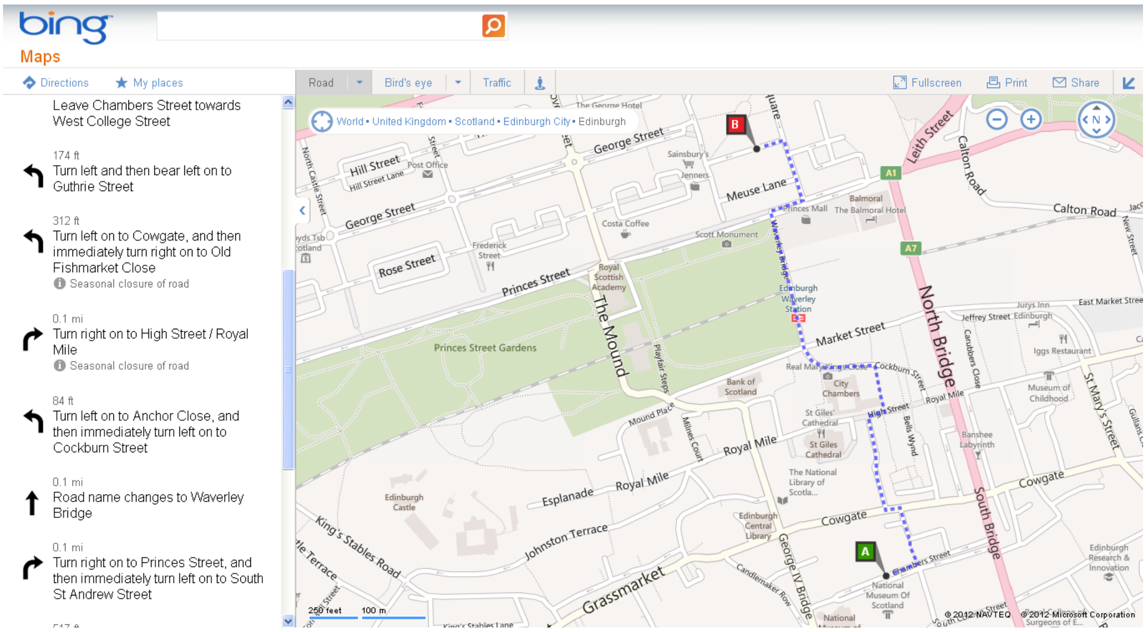


Figure 9.7: Bing Map directions for Route E-F (Bing Maps, 2012)

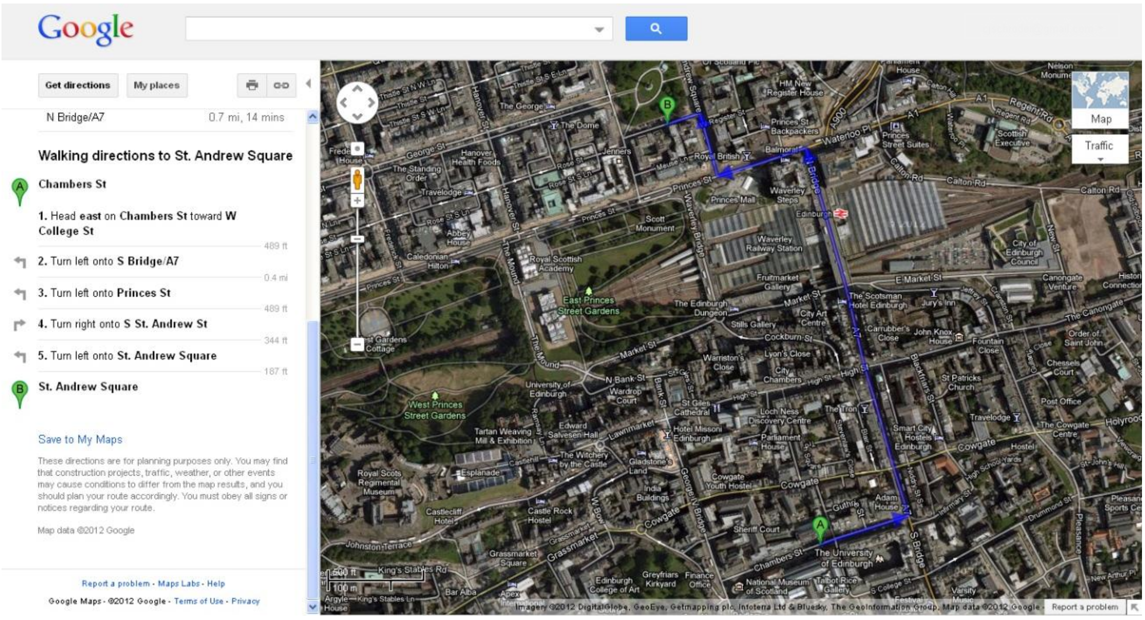


Figure 9.8: Google Map directions for Route E-F (Google Maps, 2012b)

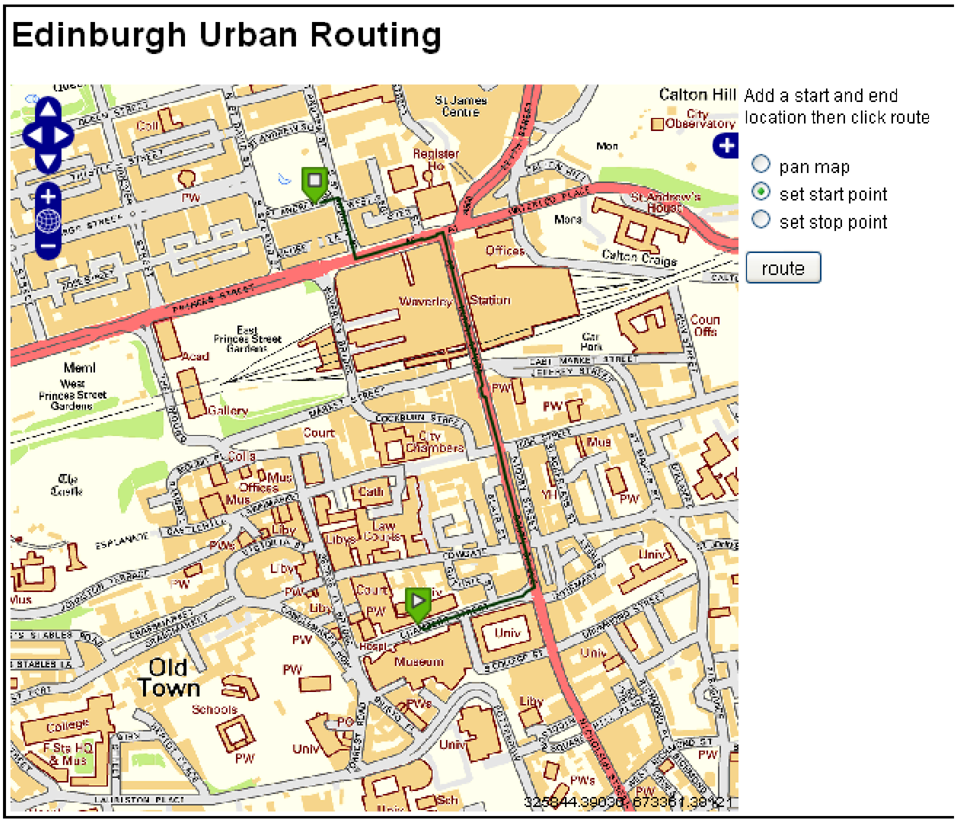


Figure 9.9: The second feature-rich route returned by the pedestrian navigation system

This illustrates that the pedestrian navigation system is taking into account whether or not the roads or paths have salient features within their surrounding area and it is returning routes that direct the navigator through more *landmark rich* areas. Navigating urban environments is made easier by the use of salient features, therefore, the pedestrian navigation system is not only providing route directions incorporating such feature, but also ensures that the routes it returns are through areas that have more salient features available. If the pedestrian navigation system did not take *landmark rich* areas and *landmark deserts* into account it would return the shortest possible routes available between the two locations, which would be the same route as returned by Bing Maps. These would not necessary be the easiest routes to follow.

Overall, the routing solution provided by the pedestrian navigation system aligns more closely to the routes that Google Maps suggests following (Figures 9.6 and 9.9) than those reported by Bing Maps. This is in part due to Bing Maps reporting the shortest possible route between the two locations rather than incorporating additional intelligence into their routing system. Google Maps, on the other hand, returns a route based on a cost associated to the overall route, calculated using a combination of variables which include distance, time to traverse it, and number of turns (Google Maps and Earth Team, 2012). While closer correlation with Google can be explained through Google Maps attempt to take cost associated to the route into account, the directions returned by Google still consist purely of street-based directions rather than taking into account other features

In the examples discussed above, four routes are reported by the three different systems. They are all very similar in length (all approximately 0.6 miles long), however, vary in the complexity and difficulty to follow, with the shortest path routes requiring more direction turns to describe the route.

Within the evaluation descriptions gathered from survey participants, a total of seven different routes were returned. Of these, four different routes were used to describe how to get from St Andrew Square to the National Museum (E-F) (Figure 9.10), whilst six different routes were used for the reverse direction (F-E) (Figure 9.11). The main routes returned involved variations of going via North and South Bridge or via The Mound and George IV Bridge. There were, however, additional routes included which went via the Royal Mile and Cockburn Street and one that directed the navigator through the St James Shopping Centre.

For St Andrew Square to the National Museum, nine individuals suggested the route via Princes Street and The Mound whilst seven suggested the route via Princes Street and North Bridge (Figure 9.10). For the National Museum to St Andrew Square, ten participants suggested the route via North Bridge and Princes Street whilst four suggested the route via George IV Bridge, The Mound, and Princes Street (Figure 9.11).

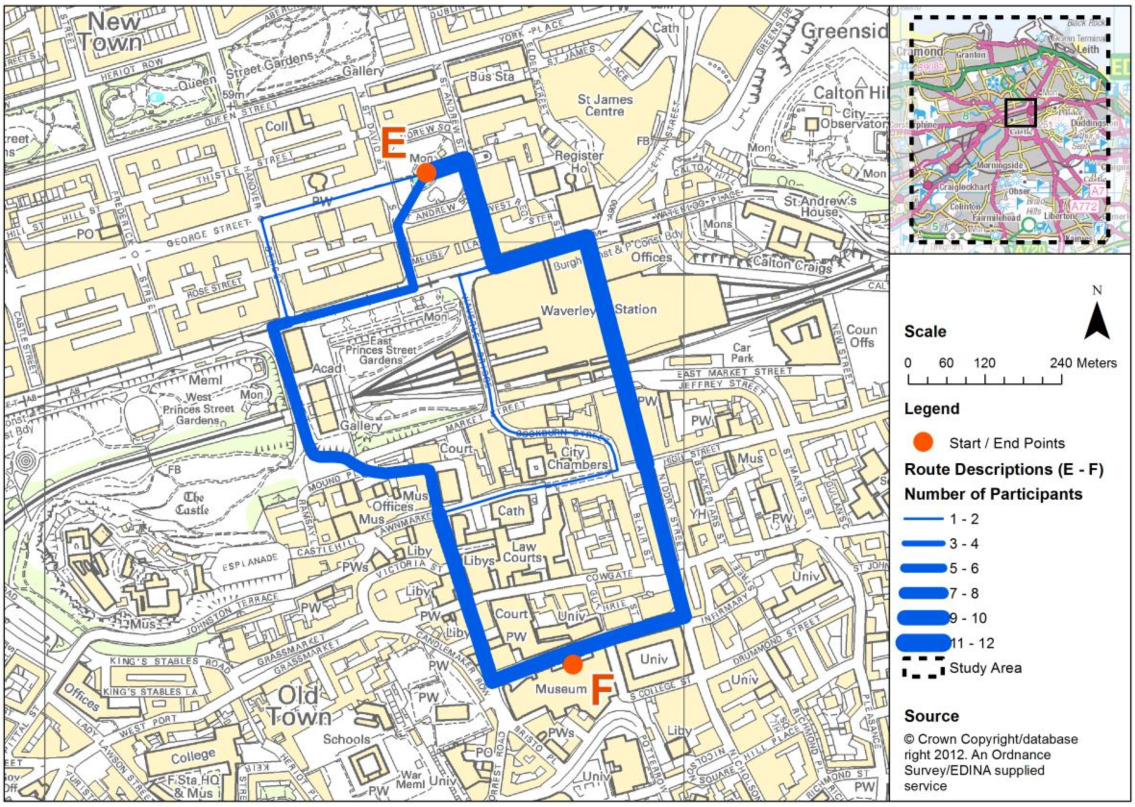


Figure 9.10: The routes (E-F) identified by the evaluation participants

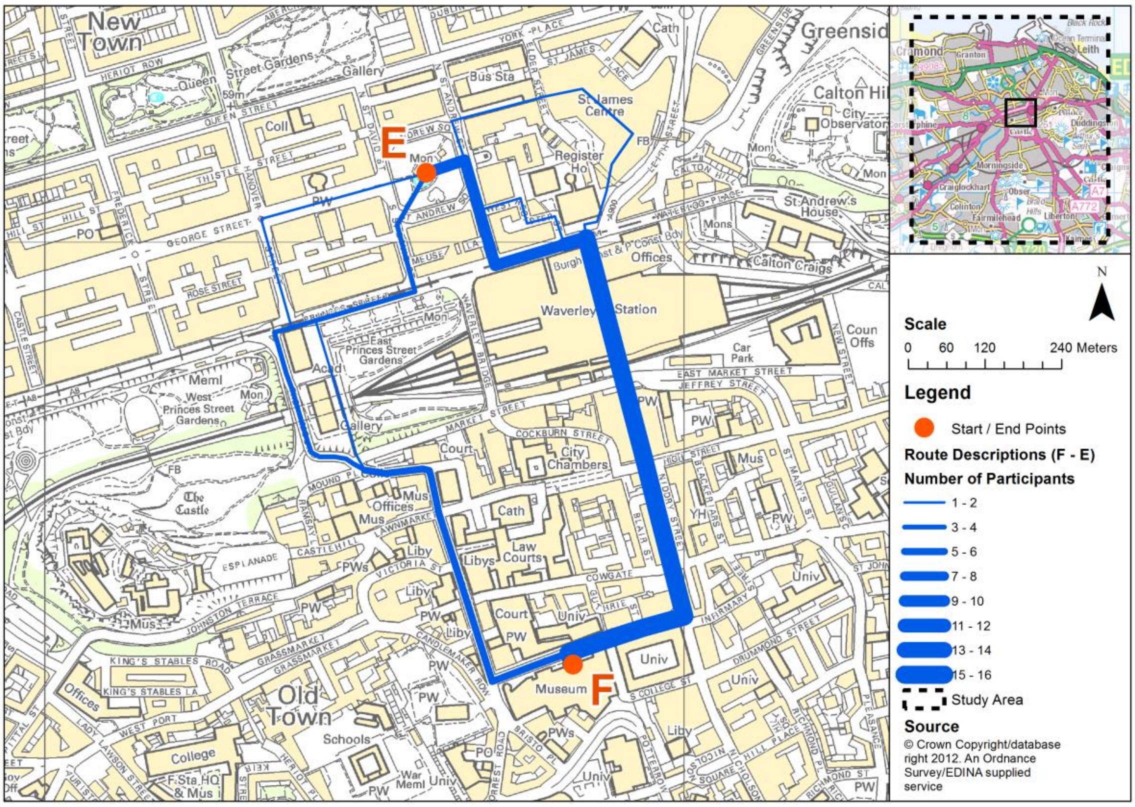


Figure 9.11: The routes (F-E) identified by the evaluation participants

In comparing the routes described by the participants (Figures 9.10 and 9.11) to the routing implemented by the pedestrian navigation system (Figures 9.6 and 9.9), it can be seen that the two routes identified by the pedestrian navigation system (E to F, and F to E) reflect the majority of choices made by the evaluation participants in providing directions between the points. Participants in the evaluation experiment however tended not to account for the subtle difference in distance depending on direction of travel, and in general participants tended to prefer the F-E route in comparison with the pedestrian navigation system. The routing implemented within the pedestrian navigation system also reflects the directions provided by the participants in choosing not to default to the shortest path when directing an individual. Of the 40 route description gathered, not one of the participants chose to provide directions for the shortest route available between the two locations.

This suggests that whilst the shortest route might be the most direct route, it was not chosen for description by the participants as it is not the one that comes to mind when asked, or due to the increased complexity of the route in terms of turns and the lack of salient features, was the most difficult to describe.

When looking at the routes chosen by the participants, the optimal route from origin to destination was identified by the pedestrian navigation system was only identified by a participant in one case. Fourteen individuals suggested a very similar route to the proposed route that involved going via The Mound rather than taking the Playfair Steps (Figure 9.11). The second most optimal route going via North and South Bridge was more popular with seventeen participants describing it. The participants used a variety of routes which may be reflective of their local knowledge, familiarity with the area and their own navigational preferences.

Neither Google Maps or Bing Maps return route directions that incorporate features of interest information in order to aid navigation. In describing the routes however, the evaluation participants were able to identify a large variety of features of interest along the routes. The comparison of the features of interest identified by the participants and the pedestrian navigation system are discussed in the following section.

9.4 Features of Interest

The inclusion of features of interest within route directions is a key aspect of the development of the pedestrian navigation system. From the descriptions collected for the evaluation, participants suggested a total of 51 features of interest along the routes. For the route E-F (St Andrew Square to the National Museum), participants identified 34 different features (Figure 9.12), whilst for the route F-E (the National Museum to St Andrew Square) participants mentioned 35 different features (Figure 9.13). These included buildings, roads and paths, statues and monuments, greenspace, and temporary features. Of the features mentioned, a third were mentioned in relation to both directions of the route whilst 41 percent of the features were mentioned only once.

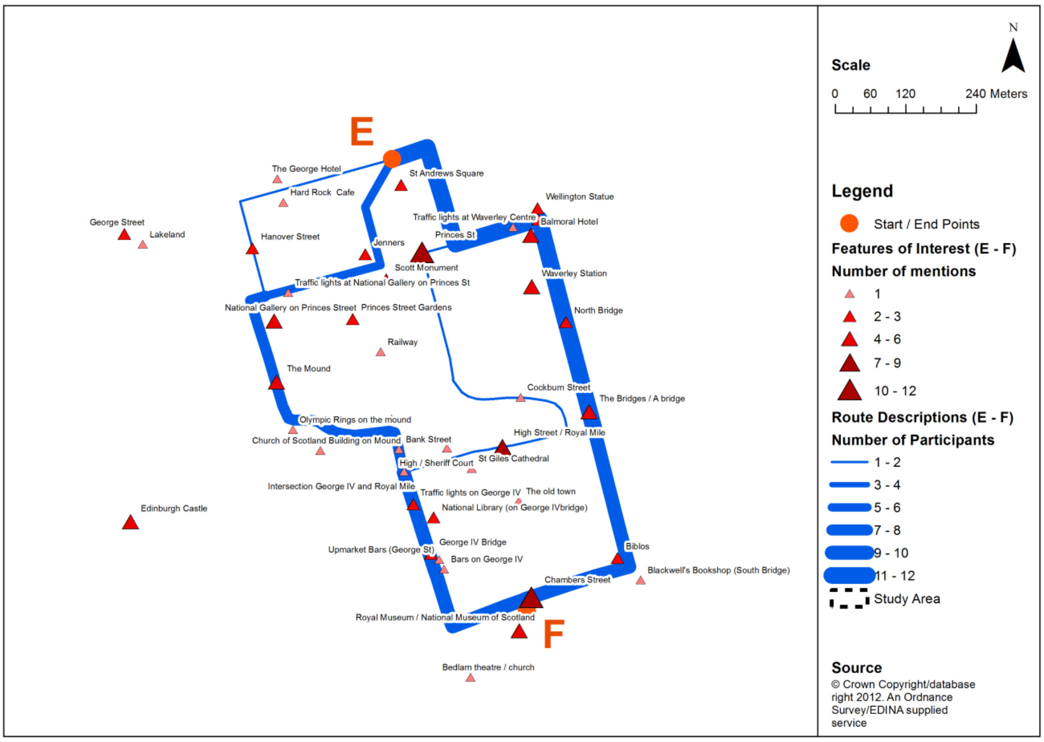


Figure 9.12: The features of interest, by route E-F, identified by the evaluation participants

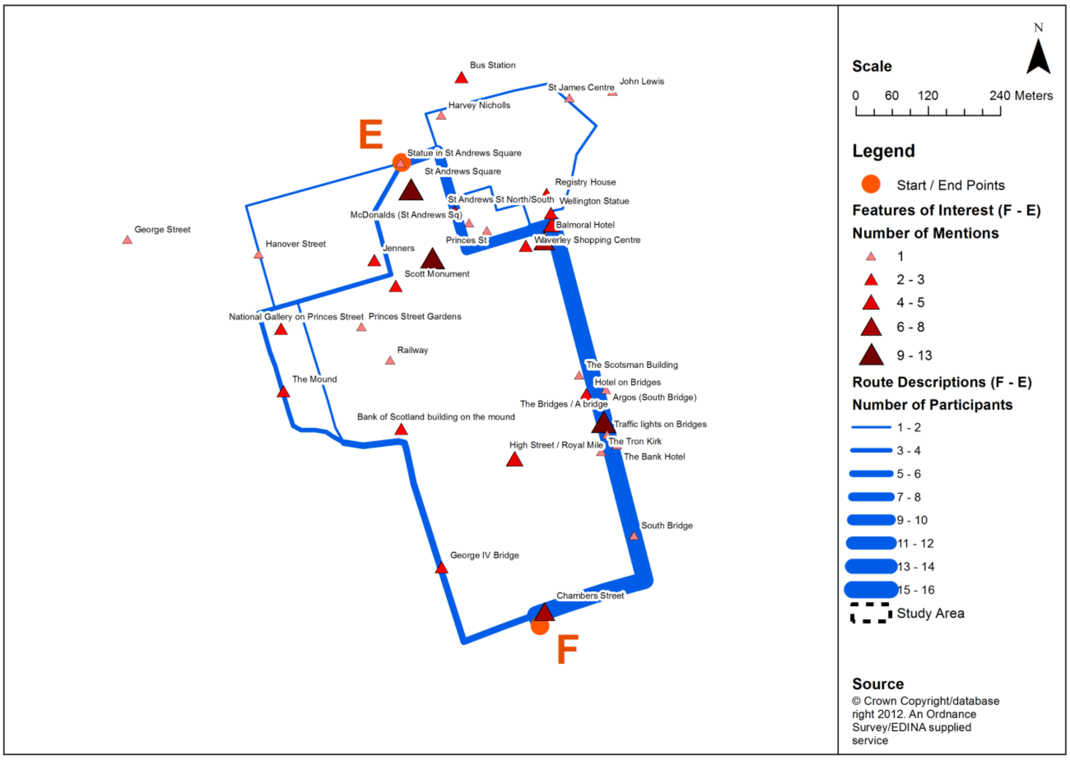


Figure 9.13: The features of interest, by route F-E, identified by the evaluation participants

The predominant feature of interest type returned by the evaluation experiments were *buildings*, which accounted for 57 percent of the features. This was followed by *roads and paths*, which accounted for 27 percent. Two features identified within the experiment fell into the other types of features identified in the feature classification schema in Chapter 4. These were Princes Street Gardens which would be categorised as a *greenspace feature* and the Olympic Rings on The Mound which would be categorised as a *temporary feature*. Additionally, two features identified by the participants currently do not fit into the feature classification schema. These were the railway lines and 'The Bridges'.

Railway lines were mentioned independently of Edinburgh Waverley Station as "it's just the gardens and railways on one side" (Participant 26). Railway lines were not identified as possible features within the initial experiments as the initial classification schema was developed using site-specific empirical data. This meant that features that did not exist within the study areas for the three experiments in Chapters 4 and 5 were not identified as feature types in the schema. They, therefore, should be added to the classification schema for features as within Edinburgh, and other cities, railway lines can be quite predominate in the urban landscape. Additionally, a wider set of empirical exercises may be required if the pedestrian navigation system was developed for areas other than Edinburgh to ensure that all features types are covered.

The other feature of interest identified was *The Bridges*. Individuals familiar with Edinburgh refer to the streets North Bridge and South Bridge by the vernacular name of The Bridges. Due to the underlying topography on which Edinburgh is built, some streets within the city centre are in fact bridges which overpass other roads and features underneath. Of the 40 participants in the study, 17 identified The Bridges as a feature of interest within their route directions, whereas only three people identified the bridges independently from each other with their prescribed name. Whilst there is a *bridge* category within the feature types, this would identify one or the other of the bridges, however, would not group them together and identify them as The Bridges. This is an important point when considering potential users of such a system. Individuals with knowledge of Edinburgh would be well placed to identify The Bridges as a navigational direction. On the other hand, however, if an individual was not very familiar with the city they may not realise or recognise the feature based on the vernacular name. For a navigator unfamiliar with the environment the prescribed name would be of more importance as it would allow for the checking of the name stated on the feature against those in the descriptions, however, the system could be extended to incorporate the use of vernacular names of features.

An issue raised by the evaluation is the use of road crossings within directions. A quarter of the participants identified road crossing features such as traffic lights, crossings, and junctions within their directions. These generally would be modelled under the *junction* feature type, however, currently no concern is given by the system in relation to the type of crossing it is. For example a saliency variable could be created related specifically to junction features that identify whether or not crossing facilities are available and the type of crossing (e.g. zebra crossing or traffic lights controlled crossing).

When comparing the features identified from the evaluation descriptions to those generated by the pedestrian navigation system the evaluation focuses on the two main routes identified by the participants that can be replicated within the system. These are the routes illustrated by Figures 9.6 and 9.9 above. For the route that goes via George IV Bridge, the route directions are shown in Tables 9.3 and 9.4. The route that uses The Bridges directions are shown in Tables 9.5 and 9.6.

Directions - National Museum of Scotland to St Andrew Square via George IV Bridge
Head North along George IV Bridge, the National Museum of Scotland should be behind you on your right
Continue past the National Library of Scotland
At the Royal Mile continue straight on and walk down Bank Street
At the Bank of Scotland Head Office turn left and walk down North Bank Street
At the South African War Memorial to Black Watch take a slight right and walk down The Mound
At the National Gallery of Scotland take a sharp right and walk along Market Street
At the South African War Memorial to Black Watch turn left and walk down Playfair Steps
At the National Gallery of Scotland continue straight on and walk along the Footpath
At the Princes Street turn right and walk along Princes Street
At the Scott Monument turn left and walk along South St David Street
You have reached your destination

Table 9.3: Directions from the pedestrian navigation system for the National Museum of Scotland to St Andrew Square via George IV Bridge

Directions - St Andrew Square to National Museum of Scotland via George IV Bridge
Head South along South St David Street, Scott Monument should be in front of you
At the Scott Monument turn right and walk along Princes Street
At the Royal Scottish Academy turn left and walk along the Footpath
At the National Gallery of Scotland continue straight on and walk up Playfair Steps
At the South African War Memorial to Black Watch turn right and walk along Market Street
At the New College take a sharp left on walk up The Mound
At the South African War Memorial to Black Watch take a slight left and walk up North Bank Street
At the Bank of Scotland Head Office turn right and walk up Bank Street
At the High Street continue straight on and walk along George IV Bridge
Continue past Hotel Missoni
You have reached your destination

Table 9.4: Directions from the pedestrian navigation system for St Andrew Square to the National Museum of Scotland via George IV Bridge

Directions - St Andrew Square to National Museum of Scotland via the Bridges
Head South along South St Andrew Street, Meville Monument should be behind you to your right
Continue past Barclays Bank Ltd
Continue past Pride of Scotland and Greggs
At the Topshop and Burton turn left and walk along Princes Street
Continue past Duke of Wellington Statue
At the Duke of Wellington Statue turn right and walk up North Bridge
At the High Street continue straight on and walk along South Bridge
Continue past Tron Kirk
At the Old College turn right and walk along Chambers Street
Continue past National Museum of Scotland
You have reached your destination

Table 9.5: Directions from the pedestrian navigation system for the National Museum of Scotland to St Andrew Square via North and South Bridge

Directions - National Museum of Scotland to St Andrew Square via the Bridges
Head North along Chambers Street, William Chambers Statue should be in front of you
Continue past National Museum of Scotland
At the Old College turn left and walk along South Bridge
Continue past Tron Kirk
At the High Street continue straight on and walk down North Bridge
At the Duke of Wellington Statue turn left and walk along Princes Street
Continue past The Balmoral
At the Topshop and Burton turn right and walk up South St Andrew Street
Continue past McDonalds
You have reached your destination

Table 9.6: Directions from the pedestrian navigation system for St Andrew Square to the National Museum of Scotland via North and South Bridge

The major features identified by the evaluation descriptions were Princes Street, Chambers Street, St Andrew Square, the Royal Mile, the Bridges, the Balmoral Hotel, the National Gallery, and the National Museum of Scotland (Figure 9.14). Three of these features related to the start/end locations of the routes, whilst the other five features were all included in the directions created by the pedestrian navigation system.


(a) (b)

Figure 9.14: Examples of the most identified salient features included within the evaluation participants directions (a) Balmoral Hotel (b) National Gallery of Scotland

A total of 32 building and statues and monuments features were identified within the evaluation participant descriptions. Of these, twelve were mentioned in the directions generated by the pedestrian navigation system, whilst eleven were not mentioned. Within the eleven features not mentioned, eight were mentioned only once by the participants. The remaining nine features were located on the additional routes identified by the participants. The features mentioned within both set of descriptions included Scott Monument, the Balmoral Hotel, National Gallery, and Bank of Scotland building (Figure 9.15). Within the streets mentioned, two were selected and used as the salient features; Princes Street and High Street. The majority of the other streets mentioned by the participants were included in the directions as the name of the road that was to be traversed.


(a) (b)

Figure 9.15: Examples of the salient features identified by both the evaluation participants directions and the pedestrian navigation system (a) Scott Monument (b) Bank of Scotland Headquarters

The selection and use of the High Street as a salient feature again illustrates the issue regarding the proper name to use when referring to a feature. To the majority of people in Edinburgh, the High Street is more commonly referred to as the Royal Mile. Within the ITN Road Network however, the road referred to as the Royal Mile is actually a combination of five different roads: Castlehill, Lawnmarket, High Street, Canongate, and Abbey Strand. Therefore, in future, the pedestrian navigation system needs to be able to incorporate where features may be known, and sign posted, by multiple names, such as the Royal Mile. The development of datasets defining vernacular geography is important not only for pedestrian route directions but for other navigation systems such as emergency response systems. These datasets need to reflect the names that local people call features within their local environments. Be it a feature on their street, in their suburb, or more generally in the town or city. Research is currently being undertaken by the Ordnance Survey alongside the English Project to develop such datasets. This dataset aims to be an alternative name gazetteer reflecting those place names which are unofficial names that do not currently appear on Ordnance Survey maps. This project asks the public to contribute names via the English Project website, and so far they have collected over 2500 vernacular names throughout the UK (Ordnance Survey, 2013).

Although clear correlation can be seen between the features of interest identified by the pedestrian navigation system and those generated by evaluation participants, subtle difference are also noticeable in the particular features used to guide navigation at individual decision points. A good example of this occurs at the junction of Princes Street and North Bridge. The descriptions provided by participants showed that the Balmoral Hotel was used to indicate the turn for the junction of Princes Street and North Bridge, however, within the pedestrian navigation system directions the most salient feature at this decision point was determined to be the Duke of Wellington Statue, as this was the only statue in the area and hence returned a high saliency value (Figure 9.16). Within the system, the Balmoral Hotel was instead used as a confirmatory cue at the junction of Princes Street and West Register Street.

Figure 9.16: Duke of Wellington statue, intersection of Princes Street and North Bridge

As the system determined the most salient feature at each decision point, and possible decision point, the system generated directions had twice as many references to features than the participant's evaluation descriptions, which on average included only five features of interest. The system extracted a number of additional features that were not mentioned by the participants. These building features were calculated as salient based on a number of the measures identified in Chapter 7, however are included within the directions by the name saliency measure. These were generated from the use of the Gazetteer of Scotland, PointX's National Points of Interest, and RCAHMS datasets. These features included shops such as Burton, Topshop, and Pride of Scotland, food outlets such as Greggs and McDonalds, and statues such as the South African War Memorial to Black Watch. This ensured that every turn (or possible turn) that was required was described with a feature of interest.

The visibility model can be observed to work where required within the turn directions generated by the system. For example, traversing George IV Bridge was included in both sets of pedestrian navigation system directions, travelling E-F and F-E. The National Library of Scotland was selected in one set of directions as a confirmatory cue, whilst in the other direction the Hotel Missoni was selected. This was due to the Hotel Missoni not being visible from the observation point approaching it from the direction of Chambers Street. At the junction of South St Andrew Square and Meuse Lane, in one direction a McDonalds food outlet is used as the confirmatory feature, whilst in the other direction the confirmatory features are the retailer Pride of Scotland and the baker shop, Greggs. A final example is of the junction of The Mound and Market Street. In one direction the National Gallery of Scotland was identified as the most salient feature, whilst in the other it was the New College (Figure 9.17). However, the visibility model did not have an effect at many of the other reorientation points as the same features of interests were incorporated for both directions of the route.

(a)

(b)

Figure 9.17: The different field of views for the approach to the decision point (a) from The Mound (b) from Market Street (Google Maps, 2012a)

The use of confirmatory cues within the pedestrian navigation system generally added beneficial information to the directions. Examples include "Continue past the National Library of Scotland" or "Continue past Tron Kirk". However, in one case it has over complicated the turn descriptions where the Duke of Wellington Statue was used twice within neighbouring directions:

"Continue past Duke of Wellington Statue"
"At the Duke of Wellington Statue turn right and walk up North Bridge"

These directions are confusing. This problem arises due to the same visibility polygons being used for the selection of both the decision point features and the confirmatory features. This means that, at the observation point, the pedestrian navigation system is looking forward within 100 metres to decide on the salient features, whereas for the confirmatory cue feature it may be looking too far ahead. This issue could therefore be solved by adding a condition into the system which states that if a feature is used to describe a reorientation, then the second most salient feature is selected for the confirmatory cue.

9.5 Gradient Descriptors

The route descriptions generated by the pedestrian navigation system include a gradient descriptor, which takes into account the change in the height of the start and end of each road or path that make up the route and changes the textual description to state whether the navigator should be walking up, down, or along the road. This was recognised in the initial three experiments as an important contextual part of the route description and thus incorporated into the directions generated by the pedestrian navigation system.

The route descriptions produced by the pedestrian navigation system used the gradient descriptors as follows:

“At the Royal Mile continue straight on and walk *down* Bank Street”
“At the [feature] turn right and walk *up* North Bridge”
“At the Scott Monument turn right and walk *along* Princes Street”

The evaluation experiment reinforces the importance of using gradient descriptors within route directions. The urban topography that lies between the two locations used within the evaluation experiment has a very distinct change in gradient. Within the directions gathered, all of the participants referred to the change in gradients in terms of walking *up* or *down*. ‘Walk up’ was primarily used when describing the route from St Andrew Square to the National Museum as it requires walking up the hill where Edinburgh Castle sits. ‘Walk down’ was primarily used when describing the reverse route. Gradient was often used multiple times during descriptions.

There were however several cases where the use of up and down were not related to the gradient of the land. For example, some people mentioned “go down to the end of the Chambers Street” and “go down George IV Bridge”. The streets referred to, within these statements, do not have an overly obvious gradient attached to them. Chambers Street does have a slight slope to it; however, it is not picked up within the pedestrian navigation system.

This could also be related to individuals having different interpretation of space and a different frame of reference for their cognitive map. For example some people in Edinburgh state that they are “going up to London” when in cardinal directions you are heading south which many relate to the down direction (with up being north). If this was to be taken into account for the pedestrian navigation system the descriptive words could be changed from up and down to climb and descend. However, the argument against this would be that the majority of participants in both the initial experiments and the evaluation study mentioned gradient simply in terms of up and down, therefore using this terminology would more accurately reflect the natural inclusion of gradient within route descriptions.

The number of mentions of gradient within the collected directions were equal with the mentions of left and right, the core turn descriptors for routes. Part of this can be attributed to the pronounced change in height between the St Andrew Square and the National Museum. However, it is argued that the use of gradient descriptors is just as important as turn descriptors when developing route directions. They should be recognised as a core part of any system that generates route descriptions. They add contextual information to the route descriptions and their use can help clarify to the navigator that they are on the right track. People can easily identify if they are walking upwards or downwards and inclusion helps to achieve the overall objective of automatically creating more natural set of directions.

9.6 Summary

Under evaluation, the pedestrian navigation system has been proven to include the same type of contextual information used to enrich route descriptions for navigation as individuals with a cognitive map of the evaluation routes. The optimal routing returns the most popular routes identified by the evaluation participants, whilst of the large variety of features of interest included in the descriptions by the participants, the most mentioned ones were also included in the system directions. The use of the gradient descriptors is also very important in natural route descriptions with all of the participants referring to gradient at least once in their descriptions. This was also reflected in the directions generated by the pedestrian navigation system.

At the base of the development of more natural route directions is the individual's perception of space. This makes automating a system to generate them an extremely difficult process as human behaviour and preferences are very hard to model. The pedestrian navigation system has been developed based on the findings of three experiments with a group of 40 students, however this evaluation has shown that the findings from those experiments are applicable to a much wider audience. The system generates more natural directions than those that only provide direction which refer to street names, however this evaluation has also shown that there is more work that can be carried out to make the system more effective.

Chapter 10

Discussion and Conclusion

Feature-rich landmark information to facilitate wayfinding is not currently included in any of the commercially available systems which provide directions for pedestrian navigation in an automated manner. Previous research has shown however, that the inclusion of such information is beneficial to users navigating in an urban environment. Issues therefore exist with current systems for pedestrian navigation regarding the lack of such information.

Several issues however, can be identified in previous research into the utility of landmark information in pedestrian wayfinding. Such research has previously focused on the creation of bespoke datasets for the purposes of the study being undertaken, limiting the wider applicability of conclusions. In addition, previous research can be seen as limited in considering the range of features identified as potential landmarks, the saliency models used to assess landmarks, and the options available for routing in relation to landmark features.

This thesis has argued that the inclusion of landmark information in automatically created route descriptions is possible, and has put forward a method by which to undertake the process using a variety of pre-existing datasets available for urban areas within Scotland. In addition, empirical evidence generated by research conducted to underpin the pedestrian navigation system, has raised a number of considerations in relation to current thinking on cognitive modelling, the use of landmarks, saliency modelling, and routing in relation to landmarks.

This chapter therefore outlines the contributions of this thesis to the body of research within this field, before providing a critique in terms of the pragmatic approach required when modelling saliency, the potential scalability of the pedestrian navigation system, the observed limitations of the approach, and potential future developments.

10.1 Main Contributions

In designing the pedestrian navigation system, it became evident that previous research in this field did not provide sufficient conclusions on which to model the rules and requirements for such a system. It was necessary therefore to undertake the landmark experiments detailed in Chapters 3, 4, and 5 to provide evidence on which to base the pedestrian navigation system. The findings of these experiments can however be seen to have raised several considerations, which have contributed to the advancement of research in this field.

10.1.1 Cognitive modelling of users

From the empirical experiments conducted in support of this thesis, it is argued that there are at least fourteen classes of features of interest that exist within the urban environment, and which are frequently included in route descriptions. In addition, it was identified that different modelling strategies are required for each of these feature types. This thesis proceeded to develop saliency variables for the three main feature types: buildings, roads and paths, and statues and monuments with the goal of automatic extraction from pre-existing and widely available datasets. The identification of other feature types and the theoretical creation of their related saliency variables was also discussed. Finally, the thesis discussed the inclusion of these features of interest within the route directions by incorporating the most salient feature at each decision point, regardless of its feature type.

10.1.2 Extended saliency model

Currently research into identifying and measuring the saliency of a feature of interest has been focused on the formal model of landmark saliency put forwarded by Raubal and Winter (2002). Yet, this formal model was not developed on the basis of empirical evidence. Indeed, Sadeghian & Kantardzic (2008) stated that “there is no prior experimental verification that the small arbitrary set of static attributes analysed in the landmark detection process is sufficient to select the most salient objects”.

Within this thesis a more comprehensive set of saliency categories has been developed based on the results of three experiments analysed in Chapters 4 and 5. Several of the fourteen saliency categories identified overlap with those measure proposed by Raubal and Winter, including façade area, shape, colour, cultural and historical significance. Differences arise, however, in relation to categories such as emotions towards features, architecture, and location. The saliency categories put forward relate to a variety of features, not just to buildings. The categories of saliency identified within this research are more inclusive of all the various qualities of a feature that could affect its saliency.

10.1.3 Identification and use of various features of interest

Predominately the research into the use of features of interest within route descriptions has focussed entirely on buildings (Elias, 2003b; Musliman *et al.*, 2010). Whist several authors have mentioned the possibility of other features acting as landmarks (Winter *et al.*, 2004), the discussion on their inclusion and measuring their saliency has been minimal (Sadeghian & Kantardzic, 2008). As stated above, this thesis progresses previous research by extending the classification schema to encompass fourteen features of interest types that exist within the urban environment and which are often included in route descriptions. The research focussed on the development of the saliency variables for the three main feature types: buildings, roads and paths, and statues and monuments. The identification of other feature types and the theoretical creation of their related saliency variables were also discussed. In addition, this thesis asserts that the inclusion of these features of interest within the route directions should incorporate the most salient feature at each decision point, regardless of feature type.

10.1.4 Feature-rich routing

Previous research has discussed a variety of methods used for routing from shortest distance, least time, or fewest turns, to most scenic, or straightest route (Dalton, 2003; Elias & Sester, 2006; Golledge, 1995, 1999a). This thesis incorporates the idea of feature-rich routing involving the recognition of landmark deserts and landmark rich areas. It is argued that routes created for pedestrian navigation should ensure that the navigator is directed, where possible, through *landmark rich* areas as opposed to *landmark deserts*, whilst still taking length of the route into account. This enables the navigator to have a set of directions that include more features of interest, thus leading to more successful navigation as previous research has shown that the inclusion of landmarks within route descriptions leads to less wayfinding errors.

10.1.5 The weighting of the saliency categories

In past research the use of weight factors have been included within the saliency models, however, the influence of each attribute was assumed to be equal (Sadeghian & Kantardzic, 2008). Within this thesis, it is argued however that within a set of saliency categories, the importance of each category varies. Therefore, within the calculation of the overall saliency of a feature of interest, weights were taken into account based upon their identified importance from the experiment in Chapter 4.

10.1.6 Visibility modelling

Defining the most salient feature at a decision point depends on the location from which you approach the decision point. A feature that is most salient for one orientation change may not be for other turns at the same decision point. This reinforces the view that saliency is relative both to other features in the field of view, and their degree of visibility (which in turn, depends on the direction of approach). An important finding in this research is that visibility is locally specific and related to the pedestrians movement through the environment, visibility should not be considered an intrinsic measure of feature saliency; rather it should be taken into account alongside saliency when developing the route directions to help determine which feature to use to direct an individual at a particular decision point. The techniques developed in this thesis for extracting the most salient feature of interest at a decision point is a significant advancement of current research on the automatic generation of route directions. It is important that a salient feature must stand out within its surrounding area, the visibility modelling was used to determine the features in the surrounding area for each decision point based on the navigator's field of view as they approach the decision point.

10.2 The Pragmatics of Modelling Saliency

A key aspect of this research is the method identified for the automated modelling of saliency. The experiments in Chapter 4 and 5 identified a set of saliency categories that a feature may exhibit and discussed how these categories related to the various feature types in differing ways. A set of related saliency variables were developed, based on these saliency categories, and Chapter 7 discussed their development.

The development of the saliency variables was automated, based on a number of existing datasets. The combination of these various dataset allowed for the identification of the features of interest and the calculation of their related saliency variables. This meant that a total of 23 different saliency variables were created. It was possible to generate a large number of these variables using the described datasets. This was true with regard to the categories based on physical structure such as size, shape, and location. Such variables were calculated using spatial functions available within PostGIS and ArcGIS. For the calculation of variables representing other categories, such as name and function, manipulation of a variety of datasets, including PointX's National Points of Interest and the Gazetteer for Scotland, was required. This manipulation included selecting the appropriate classifications from datasets and linking them to the overall features of interest through the use of unique identifiers or by spatially joining the datasets together. Several variables were created based on proxy information. For example, Historic Scotland's Listed Buildings were used as a proxy for the architectural saliency category, whilst PointX's National Points of Interest was used as a proxy for the existence of signage on a building feature.

These variables, however, do not cover all the saliency categories identified. Colour, emotions towards a feature, construction, and condition are all difficult variables to calculate. Both emotions towards a feature and the condition of a feature are extremely subjective and reliant on human interpretation. The generation of variables within these categories would require user participation and interaction with the pedestrian navigation system. With regard to the colour and construction categories, advanced image processing algorithms would be required extract this information. Such image processing algorithms could also help with the identification of the decoration category. The algorithms could utilise Google's Street View imagery in order to determine these saliency categories, and as Street View is existing data, no additional data collection is necessary. This would enable the development of these saliency variables for any urban location captured in Street View. Another method to develop such saliency variables would be to textually search available databases such as the Gazetteer for Scotland, RCAHMS's Canmore, or even Wikipedia. Algorithms would need to search the text not only for key phases, but also be able to interpret the information returned, to ensure that the appropriate feature was returned and not another feature that may be mentioned in the same text.

The automation of the creation of the saliency variables is entirely dependent on how the source datasets have been developed, collected, and classified. It is also dependent on the original intended use of the data. For example, whilst the Gazetteer for Scotland details information on important buildings, tourist attractions, and historical sites that can act as features of interest within route descriptions, it does not include information about everyday shops, restaurants and bars that are often used in directions by individuals. Another such example is evident within Ordnance Survey's MasterMap. Whilst statues and monuments are collected within the structures theme, they are collected either as polygons or points, but not both. Ordnance Survey state that monuments smaller than $8m^2$ are only captured as points, although on investigation of the data, there are monuments captured as polygons with areas much smaller than $8m^2$. This, however, still results in only a few select statues and monuments for which area may be calculated.

Additional measures of saliency, such as an individual's emotions towards a feature and condition, could be measured through user interaction with the pedestrian navigation system. Public participation with the site is a potential method for calculating those variables that are related to individual preferences and perception of features. For example, an individual could rate a feature according to whether they view it positively or negatively or whether it was in a good or bad condition. For each feature, the resulting individual ratings could be averaged to develop the saliency variable to be incorporated within the overall saliency calculations.

Finally, it must be remembered that complete consensus on what is the most salient feature in an urban environment is not in itself an achievable goal. Saliency is based on human interpretation, individual preferences, interaction with the feature, and prior knowledge of the area. Thus, datasets like the Gazetteer for Scotland have created their own hierarchy of saliency, based on the characteristics deemed important to the dataset creators (or its defined purpose) rather than the more general (and perhaps more arbitrary) values used by a member of the public.

Therefore, whilst this research has been based on empirical evidence generated by three experiments, the evaluation of the system shows that while the directions can extract the most salient features of interest available according to the parameters it is given, it does not always represent what a particular individual might consider the most salient feature in any given scenario. Such selections are subjective and highly personal, based on emotions, pre-existing knowledge, and familiarity with an area. When modelling saliency, it is necessary to use and join together a variety of data from different sources to build the feature of interest datasets that accurately represent the urban environment and reflect the saliency of the features. No single dataset contains enough information to build the complete set of required saliency variables for a pedestrian navigation system. Additionally, the development of variables relating to several saliency categories, including condition and emotions towards features, are incredibly subjective and difficult to measure and quantify in a way that is applicable to the entire population.

10.3 The Scalability of the Pedestrian Navigation System

An important consideration when developing the pedestrian navigation system was to ensure that it was scalable beyond the area of study. Whilst the system was developed based on information about the saliency of features and geographical datasets gathered for the City of Edinburgh, the results of this thesis are applicable further afield.

The centre of the City of Edinburgh was used as the study area for the basis of the pedestrian navigation system. The experiments were conducted as a means of identifying what features individuals found most salient and the reasons behind why they viewed a feature as being salient. The results from these experiments were translated into a set of saliency categories and variables that were used to measure the overall saliency of a feature. The experimental findings on which the system was developed were gathered for Edinburgh, which is a distinct city with its multi layered nature and historical centre. The saliency categories, however, can act as a set of rules that could be applied to other urban areas. The categories take into account all aspects of the features, from age and size to construction and decoration. All of the saliency categories could be interpreted and calculated for features within any urban environment. Additionally, the recognition that features other than building can act as directional aids allows for a much wider application of the work discussed in this thesis.

In selecting the centre of Edinburgh, one of the most feature rich landscapes in Scotland, the research has benefited from an ideal place to recognise what features of interest are used within directions, and what makes these features salient. However, with this in mind, further research needs to be undertaken to see how such a system performs outside of such a feature rich urban environment.

The technical development of the key parts of the pedestrian navigation system can be replicated for any urban environment within the United Kingdom. The major datasets used to identify the features of interest, in the creation of the saliency variables, and for routing are available for the whole of the United Kingdom. These datasets include Ordnance Survey MasterMap Topography Layers and ITN Networks, OpenStreetMap, and Cities Revealed data (LiDAR and Building Class). The listed buildings, scheduled monuments, and national monuments record datasets that were provided by Historic Scotland and RCAHMS are specific to Scotland, however, corresponding data is collected for the rest of the United Kingdom by various organisations including English Heritage, Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW), Welsh Historic Monuments (Cadw) and Environment and Heritage Services Northern Ireland. The final dataset that was used was the Gazetteer for Scotland. This dataset is unique to Scotland and similar databases do not currently exist for other parts of the United Kingdom. A possible solution would be to use internet sites, such as Wikipedia or TripAdvisor, to provide information that is similar to that provided by the Gazetteer for Scotland. The major issue with the data, however, is cost.

The majority of the data used within the development of this proof of concept system is proprietary and therefore the development of systems similar to the pedestrian navigation system to be developed outside of academia would incur a large cost associated with accessing the appropriate data. Currently free data sources, such as OpenStreetMap, provide some data that can be used within the system. This data, however, is limited in its completeness and is often captured at a coarse resolution (e.g. whole city blocks as compared to individual buildings) which unfortunately does not provide useful features of interest at a local level.

10.4 Limitations

While this thesis has made the best possible use of the datasets and technologies available to undertake the automated creation of pedestrian navigation routes, it must be recognised that limitations are imposed on the system by any inherent limitations within the data or technology. This is particularly evident, for example, in the implementation of datasets as 'best available' proxies in support of purposes for which they were not originally created.

A significant limitation within this research is the use of the ITN Road Network data. Although the best available street network dataset, currently, the ITN Network is not focussed on the movement of a pedestrian through the network, rather it is focussed on the movement of cars. It is, therefore, representative of network space rather than real space and as such does not take into account footpaths on either side of the road and road crossings. In the evaluation chapter, it was identified that the road crossings were an important feature, particularly traffic lights. Within the ITN Road data there is no provision of information relating to where it is possible, or safe, to cross a road. The location of crossings within route directions is an important consideration and in future a more pedestrian-orientated routing dataset that models the actual space a pedestrian can occupy would be more appropriate and preferable to use. Additionally, the requirement to manually remove ten intersections within the system shows that some routing software (in this case pgRouting) needs to be further developed to cope with multi-layer environments.

As stated, the ITN Road Network is suitable for car navigation, however, it can over complicate directions for the pedestrian, especially when the additional ITN Urban

Path data has been incorporated into the complete routing network. For example, the four decision points shown in Figure 10.1 are described as follows:

1. At the South African War Memorial to Black Watch take a slight right and walk down The Mound
2. At the National Gallery of Scotland take a sharp right and walk along Market Street
3. At the South African War Memorial to Black Watch turn left and walk down Playfair Steps
4. At the National Gallery of Scotland continue straight on and walk along the Footpath

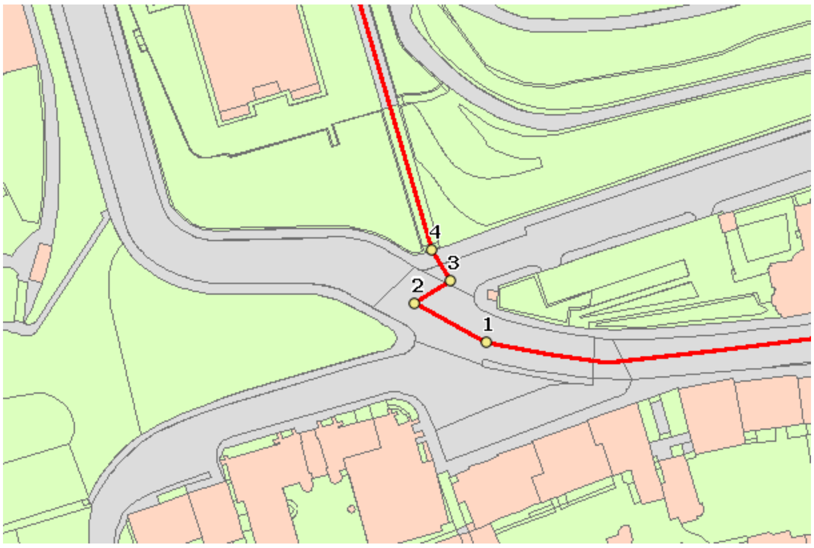


Figure 10.1: Illustration of the turn directions for The Mound to Playfair Steps

In reality, the directions would be easier to follow, and less complicated, if road-side footpaths and crossings were incorporated. This would mean that rather than walking down Market Street for ten metres, the navigator could walk down the right hand footpath and cross over Market Street to the top of the Playfair Steps. Essentially, ITN Road Network is appropriate for routing at a different, higher scale. The use of a more pedestrian friendly routing network would also change the field of view that a navigator has of a decision point. This, in turn, would increase the amount of pre-calculations required, as the number of visibility polygons and the overall saliency calculations would approximately double.

Another limitation involves the use of Dijkstra shortest path algorithm. It would have been preferable to use a more advanced heuristic routing algorithm, such as A*, however the implementation of this was hampered by the heuristic pre-coded by pgRouting which did not always return a resulting route. One benefit of Dijkstra's is that it will always find a shortest path. For this reason it was used within this research. The use of a heuristic algorithm would be more efficient, providing improved performance, especially when only a single destination point is used.

Several of the saliency variables, calculated in Chapter 7, were based on generalised assumption. The width of a road or path was estimated by dividing the total areas of the road by the length of the road. This assumed that the polygons representing the road feature are rectangular in shape and are consistently the same width. This is not always the case. Additionally, the calculation underestimates the actual width of the road as it does not take into account the width of the footpaths associated with it.

The shape complexity variable for a road or path feature also assumes that the more vertices that a road feature has the more it deviates from a straight road. However, due to the nature of the ITN Road Network, this is not always the case. For example, the ITN Road Network incorporates traffic islands which results in the road splitting into two to go either side of the island and then joins back together. This increases the number of vertices that a road feature has, thus over estimating its complexity. A simplified version of the road network should be used or data that more accurately represents a pedestrian network.

The age of a feature is another variable that was difficult to model. Based on the data that was available from RCAHMS and Cities Revealed, the age of buildings and statues and monuments were estimated to the date that they were built or erected. This, however, may not accurately represent the age that an individual may perceive the feature to be. This is particularly related to building features within Edinburgh, as new buildings are often built to look old and old buildings are often being refurbished. In addition, the RCAHMS's Canmore database only provides the age of building in terms of the century that the oldest part of it was built. This means that new buildings were recorded as old even if they were built in 1999 as they were given the age of 20th Century. It was determined that as buildings built in the 1960's were being referred to as old by the participants within Chapter 4, it was preferable to assign all buildings built in the 20th Century as old. In the future, however, a more detailed dataset providing the ages of all commercial buildings would ensure that the pedestrian navigation system would be more accurately represent this variable.

Other potential methods that could be employed to enhance the age saliency variable would be through public participation with the pedestrian navigation system. Individuals could provide feedback upon the perceived age of a feature, rather than inclusion of the specific age when it was constructed. The development of image processing algorithms could also help determine what architectural type a building feature is, from which an age value could be calculated.

It was identified within the evaluation chapter that an important extension to the pedestrian navigation system would be the inclusion of vernacular names. This is due to many participants referring to features, such as the ‘Royal Mile’ and ‘The Bridges’ within their directions, whilst the data used to develop the system does not include references to these names. There is a great deal of difficulty assigned to collecting vernacular names, as a single feature may have different names for different groups of people. Further investigation would however be required to determine whether vernacular names should be used within route descriptions. The argument could be made that if an individual was not very familiar with an area, the vernacular name may not provide a great deal of help as features are often labelled with their official names. Conversely however, the names generated from data sources such as the Gazetteer for Scotland and RCAHMS which provide the proper, official name of a feature can often provide too much detail. For example the statue on the corner of The Mound and Market Street is referred to as the South African War Memorial to Black Watch. However, it may be more comprehensible for an individual navigating the area to refer to this statue in a simpler, more descriptive, way - for example as the ‘war memorial’.

A final limitation, identified within this research, is the recognition that there are some features within the urban environment that are currently not accounted for within the classification schema for feature types. As identified in the evaluation of the pedestrian navigation system, *railway lines* were identified as a feature within the directions provided. Railway lines are currently not accounted for within the schema. This is due to only two routes being used to generate the modelling requirements for the systems, thus meaning that features that did not appear along those routes were not incorporated in the feature type schema. Whilst the test routes provided the majority of features that exist within an urban environment, there is always the possibility when looking to extend the model that some potentially important feature classes may have been omitted and would need to be modelled were the system to be implemented elsewhere. For example *water features* should be included with the natural feature category which would account for ponds, streams, rivers, lakes, and sea that may exist, or be seen from, an urban environment. Another example, especially relevant within Edinburgh, may be *ruins* such as St Anthony's Chapel in Holyrood Park.

10.5 Future Developments

As outlined in Section 10.1, this thesis has contributed to the advancement of ongoing research in the field of the automatic generation of landmark route descriptions; however there are still areas that need to be addressed.

10.5.1 The development of the remaining saliency categories

Several saliency categories that were identified within this research were not addressed when it came to developing the related saliency variables. These include the colour of a feature, the emotions individuals have towards features, the decoration on features, and the condition of the feature. These four categories are important when measuring the saliency of features and methods for their development need to be included within future work to accurately reflect the empirical evidence gathered from the experiments conducted within this thesis. The possible avenues for the development of these saliency categories have been discussed within Chapter 7 and in Section 10.2.

10.5.2 The development of the additional features of interest

It was identified from the three experiments in Chapters 4 and 5 that features used within route descriptions are not limited purely to buildings. The use of features including statues and monuments, green spaces, hills, road features, street furniture, and non permanent structures all play an important role within descriptions and therefore need to be taken into account. Within this thesis, buildings have been used alongside roads and paths, and statues and monuments to illustrate the development of the different saliency variables, the calculation of their overall saliency values, and their inclusion in route descriptions. This work should be extended in the future to incorporate the full set of feature types, as identified in Chapter 5. The identification of these features was outlined in detail in Chapter 7.

10.5.3 Inclusion of global features of interest

This thesis is concerned with features of interest that are located locally at decision points or possible reorientation points along the route. Visibility polygons are used to identify the field of view that a navigator has when approaching a decision point and within this viewshed the most salient feature of interest is selected. These local landmarks are important for the turn-by-turn nature of routes. However, global features, such as Edinburgh Castle, allow the navigator the ability to cognitively organise the space of the urban area and can aid orientation within the environment. Additionally, global landmarks can play a role as confirmatory cues within directions to reassure the navigator that they are on the right track. This research could be extended to incorporate global features of interest within the directions as confirmatory cues within the environment. This would however require expansion of the viewshed beyond the local area. In doing so, the greatly increased viewshed required to encompass global features of interest would increase the computational requirements of the system, meaning two distinct sets of visibility polygons would most likely be required.

10.5.4 Customisation of the system to user needs

Golledge (1992) proposed that computer models do not simulate the actual behaviour of wayfinders as they do not take into the account the personal preferences of the wayfinder. The pedestrian navigation system could in future be customised to suit the personal requirements of the users, in terms of selecting a preference for the type of features by which they wish to be directed. If a user specified that they were more interested in being directed by shops or tourist attractions as opposed to statues and monuments, the system could facilitate these requirements and report back directions that only included references to shops or tourist attractions. This customisation would allow the system to be personalised to the needs and cognitive style of the navigator.

10.5.5 Applicability of the saliency model to car navigation

The pedestrian was the focus of the research undertaken, however, the saliency model developed could be applied to other modes of transportation, such as car navigation. Identifying the salient features of interest along a route for car navigation would be incredibly beneficial. The various features of interest types and their associated models of saliency discussed within this thesis could be applicable to car navigation route descriptions. However, consideration would need to be given to the differences between pedestrian and car navigation, with drivers having less time to identify features of interest within the environment than pedestrians. This would therefore require careful consideration of saliency thresholds, as features of interest would have to be immediately apparent within the field of vision of the navigator while concentrating on the road.

10.5.6 Applicability of the system within rural areas

While this research is focussed on the use of features of interest within the urban environment, a saliency model and automated navigation system could be developed for rural areas. The system is designed to focus on a variety of features of interest types including natural spaces and hills, rather than just focusing solely on buildings. This means that the system could be tested to see how applicable it is to use within rural areas.

10.5.7 Applicability of the research to mobile navigation

The pedestrian navigation system was developed with the aim of being a desktop web-based system. During the period that this research was undertaken, there was a significant rise in the use of smartphones. This led to the start of mobile navigation applications becoming available. The ideas contained within this thesis lend themselves to mobile navigation and the development route navigation applications. The core datasets, including the features of interests and visibility modelling, can form the basis of such applications. These would then require the addition of different methods of egocentric route planning to be developed on top of the application. These methods would personalise the system to the needs of the user, possibly in terms of the features of interest they are familiar with, the vernacular names they use for features, or the areas they know well. This next generation of mobile navigational systems might also seek to capture data about several of the other saliency categories that were identified but not implemented in this study (including feature condition, emotions towards features, and colour) which could lead to more effective selection and recognition of landmark features for the user. The next generation of mobile navigation applications could build on the knowledge within this thesis to incorporate ideas of landmark saliency, feature-rich routing, and visibility modelling to better aid individuals in navigating the urban environment.

10.6 Concluding Remarks

This thesis began with a scenario. You had arrived at the train station in an unfamiliar city, and you needed to get to a nearby university for an important meeting. However, you had not visited the city before and you did not know the way, so you asked for directions from a passerby. What kind of information would you need to ensure that you got to your meeting both on time, without getting lost? What kind of features would you require in your directions?

The research undertaken in support of the thesis has provided an insight into answering these questions, and specified the most useful information that could have been provided by the passerby. In the absence of a passerby however, this thesis has also implemented the findings of empirical research into such questions in an automated system, which provides the type of feature-rich, natural route descriptions that are most beneficial to successful pedestrian navigation.

In doing so, the thesis can be seen to have fulfilled its five key objectives:

1. Investigation the what makes a landmark salient (Chapter 4)
2. Determine the ways in landmarks are used with route descriptions (Chapter 5)
3. Develop techniques for the automatic identification, extraction, and classification of landmarks in a urban area (Chapter 7)
4. Create a web based system that provides route descriptions which incorporate the automatically defined landmarks (Chapter 8)
5. Evaluate the automatically generated route descriptions (Chapter 9)

As detailed above, the thesis has provided conclusions which advance research into the use of features of interest in pedestrian navigation in both a commercial and academic context. The empirical research undertaken to develop, and evaluate, a rule set for modelling saliency has been argued to constitute a valuable contribution to the body of research on the use of salient landmarks. Meanwhile, the automated pedestrian navigation system developed has provided a proof of concept model for the automated inclusion of landmark information within commercial navigation systems using pre-existing and widely available datasets. Nevertheless, unavoidable issues within and limitations upon the system have been identified and highlighted. In carrying forward this research therefore, it will be important to address these within the context of the developing body of knowledge.

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Appendix I

Schroder, C., Mackaness, W. A. (2010) Giving and Receiving Directions: Requirements for Automated Pedestrian Wayfinding Technology. *Proceedings of GISRUK 2010*. (Haklay, M. & Morley, J. eds), UCL, London, 14-16th April 2010. http://discovery.ucl.ac.uk/19284/1/19284.pdf

Appendix II

Schroder, C. J., Mackaness, W. A., Gittings, B. M. (2011). Giving the 'Right' Route Directions: The Requirements for Pedestrian Navigation Systems, *Transactions in GIS*, 15(3), pp 419-438. http://onlinelibrary.wiley.com/doi/10.1111/j.1467-9671.2011.01266.x/abstract

Appendix III

The consent form, participant's survey, payment receipt, and experiment handouts used for the Landmark Experiments introduced in Chapter 3 and analysed in Chapters 4 and 5.

Informed Consent Form for Experimental Participants

Please read the following information carefully. You can also request a copy for future reference.

Experiment:	The Landmark Experiments
Organisation:	University of Edinburgh, School of GeoSciences
Experiment Supervisors:	Catherine Schroder and Dr William Mackaness

DESCRIPTION: You are invited to participate in a research study that investigates the use of landmarks within route descriptions. The experiment will involve walking two separate routes around Edinburgh's Old Town and exploring the different landmarks present along the routes. The experiment will be recorded using a digital video recorder to allow for the discussion to be transcribed at a later stage.

The data gathered will enable us to study the different types of landmarks that are used within route directions, how the landmarks are described, and where the landmarks are mentioned. We will then use this information to construct a system that will generate route descriptions based on landmarks.

RISKS AND BENEFITS: Beyond the normal risks of walking around a city (such as being hit by a vehicle) there are no physical risks involved in this experiment. Additionally, the experiment will not take place in wet weather. The money earned (10 pounds) can be seen as a benefit of the experiment.

TIME INVOLVEMENT: Your participation will take approximately 1 hour.

SUBJECTS RIGHTS: If you have read this form and have decided to participate in this experiment, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without penalty. You have the right to refuse to answer particular questions. Your individual privacy will be maintained in all published and written data resulting from the study.

If you agree with the above stated conditions and are willing to participate in the experiment, please sign below. By signing the form, you confirm that you meet the following conditions:

- You are a student
- You are at least 18 years old
- You have read the above consent form, understood it and you agree to it
- You want to participate in the above-mentioned experiment

Name: ____

Signature: ___________________________ Date: ________________

Participants Survey

Name: ____________________

Email: ____________________

Age: ____________________

Sex: Male / Female

Ethnicity: ____________________

First Language: ____________________

The degree you are working towards: ____________________

Your general area of study: ____________________

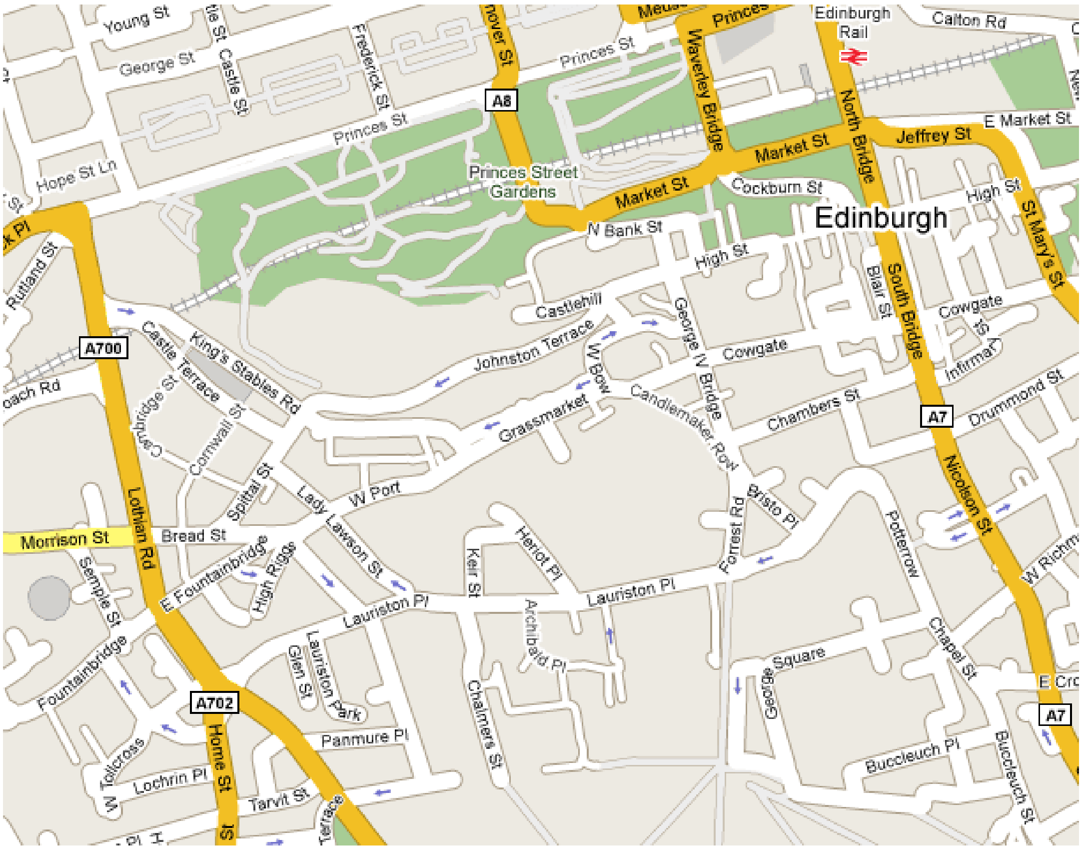
Current year of study: ____________________

How long have you lived in Edinburgh: ____________________

How well do you know the area of Edinburgh shown below?

Mark on the map the areas

- In blue - that you know very well (those areas that you frequently visit)
- In red - that you know vaguely (those areas that you infrequently visit)
- In black - that you don't know at all (those areas that you never visit)



Note: Please make sure you mark the different areas in different colours. If you alter from the colours specified please note down which areas each colour corresponds to.

Payment Receipt for Experimental Participants

Experiment:	The Landmark Experiment
Organisation:	School of GeoSciences, University of Edinburgh
Experiment Supervisors:	Catherine Schroder and Dr William Mackaness

I ____ confirm that I have

received the total sum of **£10** for my participation in the experiment detailed above.

Signed:

Experiment Participant: ______________________________ Date: __________

Experiment Supervisor: ______________________________ Date: __________

Task One Handout

The aim of this task is to identify and discuss any unusual, distinct, striking, or interesting features that stand out as you traverse the assigned route. It is important that you not only identify the feature but also discuss why you find it significant.

The instructor will lead you through the route giving instructions as to where you need turn.

The walking of the route will be videoed and this task should take approximately 30 minutes to complete.

Task Two Handout

The aim of this task is to identify the landmarks that you would use when giving a description of the route for a friend to follow. You are encouraged to discuss reasons for including each of the landmarks. You can disagree with each other and suggest alternative landmarks that you believe would be more appropriate.

Again, the instructor will lead you through the route giving instructions as to where you need turn.

The walking of the route will be videoed and this task should take approximately 30 minutes to complete.

Appendix IV

Example Transcripts for Experiments One, Two, and Three.

Experiment One

Example Transcript for Pair 19 (Participants 37 and 38), Route 1 B-A

Person	**Conversation**
Direction	And we will head up this way
P37	Well that is a big thing
P37	The theatre is the first thing I notice, the Lyceum
P38	I didn't know what it was, but it's the only white building in Edinburgh
P37	It stands out because it is a huge building on a street full of houses
P38	And its white
P37	Yeah its white
Direction	We will cross over here
P37	I have missed the Citrus Club as well
P37	A big crane but that's not always not there
P38	Yeah it won't be there
P38	Yay the castle
P37	Yeah the castle is pretty obvious
P37	And if you see the castle you normally know which way you are going, it was the way I used to find my way home in first year
P38	I still do it
P37	I have actually never seen that before
P37	Carpark, this multi storey carpark I always use for directions
Direction	We will cross over the road here and to the right
P37	I think that's a museum, but I have never been in it, or it used to be a museum or something
P37	But I have absolutely any idea of what it is
P38	Still it is low and wide so you remember it and it has those strange glyphs or whatever on them
P37	But yeah it is the same as those kind of buildings behind it, you never really know what they are but they stand out when you see them, because they are completely different to the castle and the

	tenements next to each other
P38	Yeah you know them
Direction	Lets head over this road
P38	Lots of stairs
P37	That's a landmark that I would point to people, Stereo, otherwise known as Gaia
P38	What is that?
P37	It's a nightclub
P38	I haven't seen it before
P37	That's new they have chopped all though trees down
Direction	We will cross over to the other side of the road
P38	That building is odd, cause it looks like it is standing on an old building but it is new
P37	It also looks like it is falling down a bit with all the concrete breaking off
P37	This huge tunnel is quite a big landmark feature you notice when you are walking around or if you have to walk through, and it is different at night than in daytime, they are dodgy, the same with those steps, those steps can be very dark at night
P38	How about those two?
P37	Which the two on the side or the one in the middle
P38	The two on the two sides, are they churches
P37	I don't know the one on the left definitely looks like it used to be a church, the one on the right is probably somebody's house
P38	Is it?
P37	Yeah, because they must of put gothic towers and turrets on a lot of the old buildings in Edinburgh, a lot of weird architecture, they do absolutely nothing
P37	That's quite a big feature, the International or Apex Hotel
P38	Yep true and its pink
P37	Yeah its pink, its different to everything else, although that is red
P38	The Edinburgh College of Art
P37	yeah
Direction	And we are going to head to the left
P37	These steps are quite cool, with the wee terraces on the edge
P38	It's fantastic
P37	This is all new, new stuff like the bins
P38	This is quite unique here, when I first came to Edinburgh this road was my reference point
P37	There used to be much bigger trees in this square as well, they have cut a lot of them down but have put these smaller ones in, but

	it is a lot nicer than it used to be
P38	They have cut them down?
P37	I think they are going for a European café culture type thing rather than stag do's and hen nights
P38	That building stands out
P38	It looks more newer
P37	I guess it is stuff that is new stands out more than the old stuff, cause like that is new, but it is not that new but you don't really notice it when you walk past it
P37	Yeah
P37	This was a huge landmark, but they have taken the wall round it down, so it was quite a big thing, they have kept the thing in the middle though
P37	Biddy Mulligan's that's a landmark as well, it's not a very nice pub
Direction	We are going to the left here
P38	That's a nice one in the middle of the road
P37	The big nose, the joke shop
P37	This is a really cool little street, when you walk round everyday you don't really tend to notice it till you stop and look at it
P37	There is a very good cheese shop along here though
P37	Just cause of all the different colours and the shops and the two layers, so you have the footpath up and Khushi's which burnt down
P38	Oh yeah it burnt down
P37	And that's new as well
P37	I don't walk up this way very often, I normally walk down the other way
P38	That building, that really stands outs it has nothing to do with the old buildings here
P37	And the building that used to be there was really really ugly, it was a concrete 1960's type of building, it was hideous
P37	These bits are quite cool, cause in the festival they open them up and they are all little venues and the underbelly and the whole street kind of changes
P37	Espionage another landmark, for maybe the wrong reasons
P38	Library, the National Library
Direction	We are going to go to the left
P37	And the big green dome
P38	Yeah, it's like the government something…
P37	It's the Bank of Scotland building
P38	Oh ok, I thought I was the …

P37	Courts
P37	This is something to do with the government here and there
P37	Yeah
P37	That's quite cool that building actually, the new one, lots of people often moan about the new buildings in Edinburgh and say it's not the same as the old one
Direction	We will cross down here
P38	It stands out so much, look at it, we are in a street fill of old buildings
P37	But you can't make old buildings look old, it might look old in like a hundred years
P38	Yeah but in a city like Edinburgh a building like that full of glass at least make it the same colour same stone
P37	I don't agree I think you are better to go with something opposite and some striking something interesting cause otherwise you just end up, cause you can never copy something like that because it is so intricate and expensive to make, they will never make it now
P38	Ok yeah
P37	This is a landmark that you don't necessarily want to walk over
P38	Why?
P37	Cause everybody spits on the Heart of Midlothian
P38	How about that the Big Ben thing? I don't know names
P37	This kind of city chambers thing, when you go inside there, that's quite cool, that stands out because it kind of stops with all the buildings and that's a big gap
P37	And then this thing is nice, Mr Adam Smith
P37	That stands out to me always, the 3d Loch Ness, because it is so cheesy
P37	And the ocean, that's cool on a good day
P37	St Giles obviously
P37	The Police Centre which I have always found quite random like I don't really know what it does or why it is there
P37	And the council offices where you go to get your parking permit
P37	And funny street names, like Cockburn Street and Bells Wynd
P38	Those are scary I think, the little streets, I wouldn't got there but I notice them
P37	The blue Police Box is quite different and pointless
P37	And the huge brain
Direction	We will stop here

Experiment Two

Example Transcript for Pair 19 (Participants 37 and 38), Route 2 D-C

Person	Conversation
Direction	And we will head up this way
P37	So we are in Chambers Street
P38	Opposite Biblos
P37	Yep opposite the Biblos, that a useful thing cause people can see it
P37	if they are a student they are more likely to know where Adam House is, so I would tell them Adam House, but if it was anybody else I wouldn’t bother
P38	Everyone has to registered there, lots of frustration finding it
P37	Like that big green man up there
P38	Is it Chambers?
P37	I have no idea
P38	That’s why it is called Chambers Street
P37	If you told someone about that, I wouldn't notice it
P38	What they wouldn’t notice the big statue in the middle of the road
P37	Ok so maybe I am wrong
P38	I would see it, yes
P37	I would basically tell someone to go right to the end of the road, cause it ends in a dead end so there is no point giving anymore directions apart from maybe this the Royal Museum
P38	Yeah the end of the road would be enough probably
P37	I wouldn’t notice Mr Chambers, no I wouldn’t
P38	I wouldn’t talk about that, because we don’t know what it, you can read it you have to be looking at it
Direction	At the end of this street we will turn to the left
P37	So you might tell someone to go left at the National Museum of Scotland, but it is quite confusing because it is quite a big building
P38	Left at the end of the road
P37	So left towards the Bedlam Theatre

P38	Where's that?
P37	That the big old church in front of you
P38	Oh ok
Direction	We will cross right over up here
P38	So right at the church
P37	So right at the Bedlam Church Theatre
P38	That red emo shop
P37	So go right towards the emo shop
Direction	We will go down to the left
P37	So Middle Meadow Walk would be the main thing I would be pointing people towards
P38	I would definitely say about Sandy Bells
P37	You would say Sandy Bells, if it was my friends I would say Cappadocia
Direction	We are going to head around to the right here
P38	Just before the big pedestrian road go right
P37	Past the Old Hospital which I would now like to live in
P37	So right George Heriots
P38	School
P37	Harry Potter style school, in fact is that not what it is meant to be based on
P38	This is an ugly building
P38	Yes
P38	You want the city to be modern,
P37	Yeah umm… you should of seen what it was before, it was hideous before, it was like some big concrete manky hospital
P38	But at least it was concrete
P37	I agree that I don't want to see the desks and it looks a bit scruffy but the idea was quite good, the offices look like a mess
P38	So straight
P37	Yeah go straight and go straight down there
P37	Past all the cool kids at the Art School
P38	That's the Art School right
P37	Yeah, what do you think of the Art School then
P38	They could of down something better
P37	It does look a bit like a prison
P37	It's cool though, I like it, its bold
P38	They could of use a lot more windows, it looks ugly
P37	Maybe they were trying to be energy efficiency
P37	It's another one of these buildings though, if you don't know exactly what it is its not obvious
P38	Yeah it definitely not easy to tell

P37	And the Novotel, the hotel is more obvious than the Art College cause there is huge massive sign on it and its facing me as well so as you are walking along you see it rather than having to look for it
P38	Yeah
Direction	We are going to head down here
P37	I would tell people to go down towards the Cameo
P38	But you don’t see it from here
P37	I know but…
P38	So they have to ask around
P37	I am assuming a basic level of knowledge, if they are not from Edinburgh then they won’t have a clue what I am talking about
Direction	We will take the next right
P38	After the Novotel go right
P38	Oh we are right where Richard lives somewhere around here
P37	It’s a pretty non descript street
P37	Or go right next to the burnt-out Church
P38	After you past the Novotel first right
P37	After you go past the Novotel the first opposite the Church, the burnt-out Church whatever
Direction	We will cross the road and go to the left
P38	Ok so yeah
P37	The big building site
P38	Just go right at the end of the road
P37	At the traffic lights, pedestrian crossing
P38	So what is that
P37	Golden dome, I don’t know what building it is
P38	Anyways you go to the right side of that
P37	The thing is that you have to look up at it, like as you look down a street you are looking for directions, you have to tilt you head up
P38	Yeah true...
P38	Point, that’s quite obvious
P37	Yeah big hotel, that’s pretty obvious isn't it, it isn't necessarily obvious what it is but the big huge sign on it
P38	Yeah but it says Point
P37	Like there would be no good telling someone it was a hotel
Direction	We are going to cross over these roads
P37	The castle again
P38	Yep
P38	So continue past the Point Centre
P37	The Point Conference Centre
Direction	We will stop here

Experiment Three

Example Transcript for Participants 37, Route 2 D-C

Come along Chambers Street
Towards the Museum of Scotland
At the Museum of Scotland at the end of Chambers Street turn left
Where the road forks at the Bedlam Theatre
Take the right road
Down towards Cappadocia
Go to the end of the road
Middle Meadows Walk starts on the other side
Turn directly right
Go along past the old hospital
Past Heriots school
All the way along that road
Past the Art College
At the hotel opposite by the church you turn right
The church is burnt out
Takes you down a street
The street is little and small
Then you cross the road at the pedestrian crossing
You cross over to the other side of the street
Follow the road down keeping right
You will come to somewhere called the Point, it's on your left hand side
The point big sign it's actually a hotel but you can't see
You go straight along that road
Towards Toll Cross
Towards Lothian Road
The Odeon Cinema is on the other side of Lothian Road

Experiment Three

Example Transcript for Participants 38, Route 2 D-C

Start from Chambers Street
Up the other side of Biblos
We go up the road
Towards the statue
At the end of the road we turn left
Then we see a big theatre church
There we go right
At the end of that road we turn right
Before we start going through to the Meadows
Keep it straights
Past the school
The school looks like Harry Potter
Past the old hospital
After we get past the Novotel Hotel we turned right
Then straight at that road till the end
Then left
Go past the Point Restaurant
The Point Restaurant has a big sign