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Wayfinding: a simple concept, a complex process

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Abstract

Wayfinding is the process of finding your way to a destination in a familiar or unfamiliar setting using any cues given by the environment. Due to its ubiquity in everyday life, wayfinding appears on the surface to be a simply characterised and understood process, however this very ubiquity and the resulting need to refine and optimise wayfinding has lead to a great number of studies that have revealed that it is in fact a deeply complex exercise. In this paper we examine the motivations for investigating wayfinding, with particular attention being paid to the unique challenges faced in transportation hubs, and discuss the associated principles and factors involved as they have been perceived from different research perspectives. We also review the approaches used to date in the modelling of wayfinding in various contexts. We attempt to draw together the different perspectives applied to wayfinding and postulate the importance of wayfinding and the need to understand this seemingly simple, but concurrently complex, process.

Keywords: wayfinding, human navigation, spatial cognition, environmental cognition, signage, maps

1 Introduction

On the surface, wayfinding appears to be the straightforward process of moving oneself from a current location to a desired destination in a timely manner. Humans have successfully undertaken this process employing various means of guidance such as the stars, sextants, maps, the compass and more recently global positioning systems (Fewings (2001)). Despite this, the action of wayfinding itself and the principles and factors involved are actually a complex set of processes involving many variables. Much research has been undertaken in a broad range of disciplines, particularly the environmental, behavioural and computer science fields, in examining the principles and factors related to effective wayfinding; however there has not been a systematic review of this research to date.

Wayfinding was formally defined by Lynch (1960) as the consistent use and organisation of sensory cues from the external environment. This definition guided the idea of wayfinding being the concept of spatial orientation (Arthur & Passini (1992), Jesus (1994)). This has evolved and wayfinding is now generally more accepted as the process of moving through space with the goal of reaching a spatial destination (Casakin et al. (2000), Downs & Stea (1973), Kaplan (1976), Passini (1998)). More specifically, wayfinding is the process of identifying a current location and knowing how to get to a desired destination as quickly and effortlessly as possible (Brunyé et al. (2010), Fewings (2001)). The specific way in which wayfinding is defined depends upon the research field from which the definition comes; however, the different definitions have common elements, which define wayfinding as destination guided motion (Allen et al. (2004), Brunyé et al. (2010)) due to the union of spatial and environmental cognition (Kitchin (1994), Passini (1984b)) to allow people to make a string of decisions using cognitive and behavioural abilities to find your way through the built or natural environment, with or without the use of external representations of the environment such as maps, signs or GPS systems (Casakin et al. (2000), Fewings (2001), Golledge (1999)).

Fundamentally, wayfinding is the process of finding your way to a destination in a familiar or unfamiliar setting using cues given by the environment. Within this framework, wayfinding can be broken down into three specific but interrelated processes: decision making (and the development of a plan of action), decision execution (transforming the plan into appropriate behaviour at the right time and place), and information processing (comprised of environmental perception and cognition, which are responsible for the information basis of the two decision related processes) (Apelt (2008), Arthur & Passini (1992)), Passini (1998), Passini (1984b).

This paper will examine the motivations for investigating wayfinding, discuss the associated principles and factors involved from different research perspectives and review the ways in which wayfinding has been modelled to date. We attempt to draw together the different perspectives applied to wayfinding and postulate the importance of wayfinding and the need to understand this seemingly simple, but concurrently complex, process.

2 Motivations for Investigating Wayfinding

Wayfinding is of interest to transportation and behavioural scientists, engineers, designers and architects for a number of reasons. Firstly, if people are able to find their way in a built environment in an efficient manner due to the correct placement, position and size of signs, maps and other wayfinding aides, then the flow of people during peak periods in places such as train and bus stations, airports and malls will be such that they will be able to reach their desired destination as quickly as possible, with minimum confusion and disorientation. An extreme example of this occurs during an emergency evacuation of a building. This is wayfinding at its most functional: reaching a place of safety (the evacuation point) in the shortest time possible (Fewings (2001)). If the principles and elements of wayfinding are understood, then spaces can be designed to ensure that this process can be undertaken as quickly and efficiently as possible. This is of particular importance for places like transport terminals, particularly airports.

Airport terminals are often characterised by confusion and disorientation (Arthur & Passini (1992), Seidel (1982)). The lack of a generic airport terminal design, combined with different locations and operations of critical points such as check-in counters, security screening points and gates can contribute to this. Additionally, many passengers are first time users, others are unfamiliar with the particular airport, some come from different cultural backgrounds, others are unfamiliar with the language used and some are often time-constrained and nervous, all of which can put them into a stressful state (Raubal (2001)). If the evacuation of the building is required, stress and confusion levels can escalate and passengers must rely on the correct placement and accuracy of signs and maps in order to be able to evacuate the terminal as quickly as possible. This was not the case in 1996 at Dusseldorf Airport where the deaths that occurred were attributed to the communication of wrong directions and poor architectural design (Raubal (2001)).

Investigating wayfinding is also of interest due to laws regarding equity for people with disabilities. In 2009 four million people in Australia (18.5% of the population) reported having a disability, and it is estimated that by 2050, approximately 50% of people aged over 55 will have difficulty with their mobility, vision or hearing (Australian Bureau of Statistics (2009), Australian Human Rights Commission (2011)). In the United States of America, Bureau of the Census statistics state that nearly 10 million people have difficulty reading or are unable to read printed signs from a normal viewing distance, and in the United Kingdom over one million adults are so visually impaired that they cannot read signs placed inside buildings or in the external environment (Fewings (2001)). For those in the population with impairments to their mobility, hearing and vision, wayfinding can become more complicated. As a result there are laws that govern how to cater for disabled persons. In Australia, laws and codes such as the Commonwealth Disability Discrimination Act 1992, the Human Rights and Equal Opportunity Commission Act 1986, Disability Discrimination Act 1992 and the Building Code of Australia (BCA) require that persons with a disability must be able to access any building that the public is allowed to enter or use and to have access to any goods, services or facilities available to other customers or visitors. A better understanding of wayfinding may increase efficiency and effectiveness of the use and design of public buildings and spaces for people with disabilities to allow them to make their way from their current location to a desired destination more easily.

The frustration felt when a person is lost or disoriented due to illegible, missing or incorrect signs is a common experience. A survey of North American airports by JD Associates (2010) found that airports can best facilitate passenger progress and improve satisfaction by focussing on key elements, one of which was the clarity of signage. Airports Council International (2011), through Airport Service Quality, have taken this further by releasing a best practice report on wayfinding, with a particular focus on signage. The wayfinding good practice guide for Australian international airports, published by the Australian National Passenger Facilitation Committee (2011) also focusses on the importance of signage and provides a sign design guide. The understanding and correct application of the principles and elements of wayfinding will help to reduce frustration, leading to improved customer experience.

In transportation hubs, particularly airports, passenger experience is an emerging issue as it plays a large role in a passenger's opinions of an airport (Churchill et al. (2008)). Surveys have shown that wayfinding is regarded by passengers as the third most important variable in terms of level of service in an airport (Correia et al. (2008), de Barros et al. (2007)). The Airport Service Quality (ASQ) survey by Airports Council International (2012) measures the performance of an airport terminal terminal and has 'ease of finding your way through the airport' as one of its metrics. The World Airport Awards uses data from a range of surveys that ask airport customers to rank product and service factors, one of which is 'terminal signage' (SKYTRAX (2012)).

Wayfinding is also important in addressing management strategies, including directing passengers to revenue-generating activities such as retail outlets. Similarly, wayfinding may be influenced by security strategies, staffing and a range of other perspectives. Airports therefore, like other transportation hubs, need to find a balance between direct and directed wayfinding.

The Great Ormond Street Hospital project is an example of how a wayfinding system can be used to make navigation easier, memorable and enjoyable. Existing buildings were given a colour identity to make navigation easier. Additionally, each ward was designated a different animal character designed to be appealing to children of all ages, and made each floor colourful, interesting and memorable for navigation. The correct application of wayfinding principles, together with forward planning and vision, can be used to give an area, or city, a sense of identity; an example of this is the Bristol Legible City Project.

The Bristol Legible City Project aims to make the city more accessible and enjoyable for visitors and residents through the implementation of identity, information and transportation projects. These projects included creating distinctive places by using art installations, the creation of a tourist information centre, and the creation of a graphic identity for the city, with consistent typeface for city signs and a standard palette of colours for icons and pictograms. Integral to this were wayfinding projects that included the most comprehensive pedestrian signing system in Europe, a feature of which are monolith panels located at major junctions and city spaces. Through text and map information, these panels help the user identify where they are and help them plan their journey. The combined effects of these projects is to provide information that is clear and unambiguous, encourage people to explore the local area, provide a sense of welcome for visitors and provide a better understanding of the area's attractions.

Finally, the cost associated with being lost is tangible. Lost staff time, reduced staff concentration due to providing directions, lost business, missed appointments or delayed meetings, potential lawsuits due to a lack of accessibility, failure to meet legislative or operational targets such as inbound or outbound passenger processing times, and injury or death during an emergency situation are all areas of costs for businesses (Arthur & Passini (1992), Carpman & Grant (2002)).

The motivations to investigate wayfinding go beyond wanting to stop people from being lost, however in order to satisfy these motivations, the principles and factors affecting wayfinding must be investigated and understood.

3 Principles of wayfinding

Downs & Stea (1973) proposed that wayfinding in the real world could be broken down into a four-step process comprising of

- orientation: when a person finds out where they are with respect to nearby landmarks and the required destination;
- route selection: choosing a route that will eventually lead to the desired destination;

- route control: the constant control and confirmation that the individual is following the selected route; and
- recognition of destination: the individual's ability to realise that they have reached the desired destination.

Downs & Stea (1973) also provided a framework that assessed the success of a wayfinding system. A successful wayfinding system is one that allows a person to recognise their correct location at the start of a journey as well as establish their successful arrival at their destination. Such a system strengthens a person's belief that they are travelling in the correct direction and allows the person to recognise their location and orient themselves within the relevant space. Importantly, Downs & Stea (1973) state that a successful wayfinding system allows a person to identify the location of potential hazards and to escape safely in an emergency.

The design of an environment, whether it be a building, a park or city is an integral part of wayfinding. A well designed environment encourages comprehension of the environment and can assist users to find their way and maintain a sense of direction and orientation. Connell et al. (1997) proposed principles of universal design, outlined in Table 1, in an attempt to guide designers, engineers and architects design environments that are not only functional, but are also conducive to wayfinding.

Types of wayfinding have been identified by Fewings (2001) as recreational, resolute, or emergency. Recreational wayfinding allows an individual the opportunity to solve problems that itself can be a source of satisfaction and enjoyment. Here, time is not an issue, compared to resolute wayfinding where when the main purpose is to find ones way in the most efficient manner. The complexity of the environment impacts directly on the time taken in this kind of wayfinding. In emergency wayfinding, the only important factor is reaching the destination as quickly and as easily as possible. In a transportation hub like an airport, resolute wayfinding is the most common type, although if time permits, recreational wayfinding may emerge where passengers access retail outlets in the airport.

4 Factors involved in wayfinding

Wayfinding is an interplay between an individual's characteristics, such as age, gender, cognitive development, perceptual capability, spatial ability and, mental and physical condition, and the characteristics of the environment, such as size, luminosity, signage and structure (Allen (1999), Kikiras et al. (2009), Timpf et al. (1992)). There is also an interplay between the individual characteristics (for example age and gender influence spatial and cognitive abilities) and the environmental characteristics (luminosity can alter the effectiveness of signage). In a setting like a transportation hub, the diversity of users present increases the complexity of wayfinding.

4.1 Human factors in wayfinding

The human elements associated with wayfinding are spatial orientation, cognitive mapping abilities, route strategies, language, culture, gender and biological factors. Lynch (1960) was one of the first to establish an association between a person's spatial orientation and their physical environment. Spatial orientation is defined as a person's ability to form a cognitive map (Arthur & Passini (1992), Jesus (1994), Downs & Stea (1973), Tolman (1948)). Kitchin (1994) states that cognitive mapping is a marriage between spatial and environmental cognition where the former is the internalised reflection of space in thought and the latter is the awareness that people have about environments. A cognitive map is a person's internal representation of the experienced world and involves processes that allow people to acquire, code, store, recall and manipulate information about their spatial environment (Downs & Stea (1973)). Table 2 summarises the cognitive terms frequently used when discussing wayfinding.

Successful spatial orientation occurs when a person can form a suitable cognitive map of the environment in order to establish their position (Casakin et al. (2000)). Once this orientation has been obtained, the shortest and most efficient route from their current position to a desired destination is quickly identified (Seneviratne & Morrall (1985), Ueberschaer (1971)). Route choice is affected by implicit strategies that minimise the mental and physical effort involved in moving through the environment when there is no obvious correct decision (Christenfeld (1995), Conroy Dalton (2003), Hochmair & Karlsson (2005), Hölscher et al. (2006), Seneviratne & Morrall (1985), Wiener & Mallot (2003), Wiener et al. (2004)). These strategies include least angle strategies, where the route chosen is the one that deviates the least from the global direction of the destination (Conroy Dalton (2003), Hochmair & Karlsson (2005)), initial segment strategies, where routes are chosen on the basis of initial straightness from the origin (Bailenson et al. (2000)), and choosing routes which contain the fewest landmarks and turns (Seneviratne & Morrall (1985)). Sometimes, due to people's different preferences, a strategy is chosen even if it results in selecting a relatively inefficient route (Brunyé et al. (2010)). Table 3 shows the different route selection choices and strategies.

Successfully obtaining spatial orientation depends on a person's spatial ability. This is a person's ability to perceive their surroundings with sensing and cognitive mechanisms (Lawton (2010)). Some people find it easier to find or locate specific places than others (Anacta & Schwering (2010)). Additionally, language used to communicate directions impacts on a person's ability to successfully form spatial orientation, and hence undertake successful wayfinding. Different people prefer or respond to one or more of cardinal directions, clear route instructions, exact distances, relative frames of reference, or others prefer approximations based on landmarks (Anacta & Schwering (2010)). Using verbal directions instead of, or in addition to maps can cause the formation of spatial orientation, and hence wayfinding, to go awry (Allen et al. (2004)).

Culture also affects the way spatial information is used (Whorf (1941)). Research has been shown that people who use a language with more differentiation perceive reality differently from those who use a language with less differentiation (Carroll (1956), Frank (2009)). Spatial decision making and wayfinding is impacted by the cultural and social situation of an individual; this can be observed not only between countries sharing languages, but even at the level of different districts of a city or in separate departments within an organisation (Frank (2006)).

Differences in vocabulary and terminology, geographical style, cultural meaning of terms and in conversation style (Grice (1989), Frank (2009), Lawton & Kallai (2002), Montello (1995)) also exist. Frank (2009) proposed that people living in different cultural groups perceive the world differently because the processes and structures of the mind develop in response to the unique experiential and socialisation forces to which it is exposed. Montello (1995), provides a counter-argument to this and states that a large amount of spatial cognition faced by humans during their development process is essentially the same. Language and culture, however, are not the only human elements that affect wayfinding. The impact of gender on spatial abilities and wayfinding is an area that has received substantial interest (Linn & Petersen (1985)).

Studies have found that differences exist in male and female spatial navigation and performance (Chai & Jacobs (2009), Jonasson (2005), Linn & Petersen (1985), Malinowski & Gillespie (2001), Tlauka et al. (2005)) with men usually performing better than women in many spatial activities in wayfinding (Chen et al. (2009), Contreras et al. (2012), Lawton & Kallai (2002), Lawton (2010), Malinowski & Gillespie (2001)). Spatial anxiety is also experienced differently, with women showing greater spatial anxiety than men (Barkley & Dye (2007), Gabriel et al. (2011), Lawton & Kallai (2002), Malinowski & Gillespie (2001)). It has been shown that spatial performance and the effects of stress are negatively correlated (Quaiser-Pohl et al. (2006), Titze et al. (2008)).

The navigational strategies used for wayfinding also differ. Men seem to prefer and rely on distal cues such as hill lines that give information on orientation and direction (Barkley & Dye (2007), Chai & Jacobs (2009), Fortenbaugh et al. (2007)). In comparison women depend on exact, pinpoint cues such as landmarks to identify a visual scene and form spatial orientation (Barkley & Dye (2007), Chai & Jacobs (2009), Lawton (2010)). Men have also been shown to be more accurate in navigating tasks when directional information is given (Chai & Jacobs (2009), Lawton (2010), Levy et al. (2005), Postma et al. (2004)), however women have a better object memory and object-location memory than men (Levy et al. (2005)).

Gender differences in spatial ability (Lawton (2010)), which include all the cognitive procedures used when learning an environment and trying to comprehend correlations between its elements (Lawton (2010), Timpf et al. (1992)) also exist. Types of spatial ability include mental rotation, spatial perception, spatial visualisation, object location memory, and dynamic spatial ability.Studies have found that males score significantly better in mental rotation, spatial perception tests and dynamic spatial ability (Cherney & Collaer (2005), Collaer & Hill (2006), Halpern & Tan (2001), Jonasson (2005), Lawton (2010), Linn & Petersen (1985), Silverman et al. (2007), Titze et al. (2008)), and only slightly better than females in spatial visualisation (Linn & Petersen (1985)). Females perform better in object location memory tests (Barkley & Dye (2007), De Goede & Postma (2008), Lejbak et al. (2009), Levy et al. (2005), Postma et al. (2004), Voyer et al. (2007)), which reinforces findings that show women's tendency to use nearby landmarks and men use distal landmarks for navigation (Lawton (2010)). The gender differences in spatial ability is thought to be a result of human evolution as a function of division of labour (Silverman et al. (2007)). Biological factors can also account for the differences in the spatial performance and ability between genders.

Testosterone levels, or exposure to testosterone, has been shown to increase performance in navigational tasks (Halpern & Tan (2001), Jonasson (2005), Lawton (2010)). There are conflicting results on the effect of oestrogen levels in women during the different phases of their menstrual cycle and their spatial performance (Chiarello et al. (1989), Gabriel et al. (2011), Halpern & Tan (2001)). Brain organisation has also been attributed to the differences in spatial performance. The more pronounced right hemisphere on males is attributed to better performance in spatial tasks as this part of the brain is engaged during spatial processing (McGlone (1980)). Further details on cognitive studies investigating the impact of gender, language culture and biological factors on spatial skills, performance and wayfinding are summarised in Table 4.

4.2 Environmental factors in wayfinding

People's understanding of built environments, especially buildings, their elements and functions even when they have a incomplete knowledge of the environment, is generally informed by their intuitions and expectations of an environment. These are a result of their experiences with the elements of a built environment and its communication mechanisms (Frankenstein et al. (2010)).

Lynch (1960) classified the elements of the built environment as paths, edges, districts, nodes and landmarks. These elements do not exist in isolation, but instead regularly overlap and interweave with one another. The first of these elements, *paths*, are the passages along which an individual moves and include streets, walkways, railroads, canals and transit lines. They are the most predominant feature of a built environment due to their functional necessity to allow people to move from one location to another. They allow for a directional quality and contribute to a person's sense of scale in terms of distance travelled and distance to cover. *Edges* are the boundaries between two areas and act as lateral references. Examples include walls, shores, edges of development and railroad cuts, and while they are not as dominant as paths, they play an important role in organising a built environment. Edges are an important organising feature, particularly in the role of holding together generalised areas. The next element, *districts*, are sections of an environment which have a recognisable, common character. They are generally internally recognised by an individual and are sometimes used as external reference points as a person passes or travels towards them. *Nodes* are strategic points where an individual can enter an environment and are generally a junction or convergence of paths, places of a break in transportation or a crossing. Nodes are found in all environments and since decisions must be made at these places, people's interest levels are generally more heightened at these points, making them logical places to install maps and directory boards. The last element, *landmarks*, are external reference points such as towers, domes, hills, signs or buildings. These points are generally local and only visible to restricted neighbourhoods. These elements, particularly landmarks, play an important role in the everyday spatial tasks of wayfinding and navigation (Caduff & Timpf (2006), O'Neill (1991a), Richter (2007), Tom & Denis (2003)), however communication mechanisms such as maps and signs are also vital factors. These elements are shown in Figure 1, with examples of these elements from airports.

Maps and signs are wayfinding devices (Lynch (1960)) that provide information for orientation, direction for decision making and visualise the connectivity between a current and desired location. They identify the location of, and provide the relevant information for, further decision making (Apelt (2008)). Maps facilitate wayfinding and are usually provided as a large scale diagram within or outside a building, but can also be provided via online means or as a pamphlet (Fewings (2001)). The elements of good map design, outlined in Table 6, (Apelt (2008), Hölscher et al. (2007), Thorndyke & Hayes-Roth (1982)) include the organisation of the environment into clear spaces and ensuring that the map remains uncluttered while showing enough information while showing all the elements of a built environment.

Signs provide a one-way form of communication and convey facts and information about environments without ambiguity. They direct, inform, control and identify, and fit into one of three basic sign types: directional, identification or reassurance (Apelt (2008), Fewings (2001)). Directional signs, which often include symbols, arrows or both, are generally found in buildings and cities and are used to direct people to a place, an object or an event. Identification signs identify an object, destination or place. Directional and information signs must be positioned in well-lit places at critical points (such as nodes and decision points), be noticeable and unobstructed, be legible, and oriented so that they relate to the actual environment (Apelt (2008), Tzeng & Huang (2009)). Reassurance signs signal confirmation to an individual that they are headed in the right direction. These signs should be placed past decision points to provide the user reassurance of the correct direction of travel (Fewings (2001)). A good signage system within an environment must use consistent design elements of size, colour, lettering and symbols. When combined with correct lighting, it is more likely to be noticed by users (Fewings (2001)). Research on the environmental factors that impact on spatial orientation, cognition and wayfinding performance is summarised in Table 5.

Successful wayfinding is an interplay of human and environmental factors. Human elements are used to make decisions which are based on information about the characteristics of an environment. These decisions must be transformed into actions in order to reach a desired destination (Casakin et al. (2000)). Decision making and execution requires individuals to match the representation of the environment with the environment itself (Arthur & Passini (1992), Passini (1984a)). The complexities involved in this process have led to the formulation of models which can represent wayfinding.

5 Modelling Wayfinding

Modelling the wayfinding process investigates the interactions in this process and allows the examination of which factors are the most important and influential. Cognitive studies and models of wayfinding endeavour to understand psychological variables and processes such as cognitive mapping, spatial reasoning and decision making. More quantitative models try to produce a final measure for wayfinding. The value of this measure indicates the 'goodness' or ease of wayfinding for a particular built environment and allows for the comparison of wayfinding between different built environments.

5.1 Cognitive Studies and Models

Research by cognitive and behavioural psychologists has helped define issues such as memory, cognitive mapping, spatial recognition and information processing. It has furthered the understanding of how the physical world is interpreted, how plans and actions are formed and how these plans are executed in order to navigate to a desired destination. Outcomes from this research have been useful and have provided information that can be used to establish practical guidelines on how public spaces should be built to facilitate wayfinding. However, the studies themselves have had to be designed so that participants have to distinguish between the processes of route planning and plan execution. This is because wayfinding consists of a number of smaller problem-solving tasks (Kaplan & Kaplan (1982)): start from a known destination, attempt to reach an intermediate sub-goal in order to reorient oneself and decide which direction will lead to the next sub-goal, with the process repeating until the final destination is reached.

5.1.1 Cognitive Models

Cognitive research studies of wayfinding use tests such as map sketching, direction pointing, distance estimation and giving route directions as well as in-situ observations of participants to determine factors that influence wayfinding performance. These factors include a participants' spatial processing abilities, familiarity with the environment, the presence of landmarks and the complexity of the environment's layout. The cognitive models that use these results distinguish between the process of route planning and plan execution (Gärling et al. (1984), Kuipers (1978), Kuipers et al. (2003), Timpf et al. (1992)). Spiers & Maguire (2008) used retrospective verbal report protocols, eye tracking and reality simulations to confirm that route planning is a sequential and hierarchical process with clear distinctions between route planning and action planning. Gärling et al. (1984) suggested that route planning goes through a number of hierarchically organised stages: firstly, information about the destination is accessed or obtained; secondly, any stop-over points are decided upon; next, the order of stopping points is decided; and finally, the means of travel to the destination is decided. This process is distinguished from that of travel plan execution due to the different cognitive skills used. The model by Timpf et al. (1992) comprises of three different levels of reasoning, also reinforces the distinction in the cognitive processes required between route planning and plan execution. The three levels, plan - which involves making a plan of the route; instruct - the stage when instructions are produced; and drive - the stage when the instructions are carried out, highlight the different cognitive skills required to carry out a single navigation task. A major limitation of cognitive models is that it is difficult to determine the reasons or intentions of the different actions performed by the subjects (Spiers & Maguire (2008)).

5.1.2 Verbal Protocols

To overcome this limitation, verbal protocol studies, where subjects talk aloud during the required wayfinding tasks to describe their thoughts, or describe the process at an interview after the completion of the task, are often implemented in cognitive research studies of wayfinding (Passini (1981), Passini (1984a), Titus & Everett (1996), Dogu & Erkip (2000), Kato & Takeuchi (2003), Chebat et al. (2005), Hölscher et al. (2006)). Following the completion of the wayfinding task, the results of the verbal protocols are classified, examined and analysed to understand the cognitive task in question and the strategies used by participants. The results from these studies reinforce the existence of the distinction between the two core stages to wayfinding: route planning and plan execution (Passini (1981), Passini (1984a)). Further, route planning was found to always contain two parts: a behaviour component (for example, turn right) and a location/landmark specifier (for example, at the train station). Passini (1981) concluded that wayfinding could therefore be thought of as a process in which route plans are set up and executed at the appropriate time and place leading finally to the required destination. Passini's conclusion has since been verified by other studies (Chebat et al. (2005), Dogu & Erkip (2000), Hölscher et al. (2006), Kato & Takeuchi (2003), Titus & Everett (1996)). Cognitively based computation models have used these results to investigate how spatial knowledge is stored, used and what cognitive processes are used.

5.1.3 Cognitively Based Computation Models

Cognitively based computation models simulate a wayfinder, or agent, that can solve route planning tasks with the aid of cognitive map-like representations. The TOUR model by Kuipers (1977, 1978) is the first of these models. Heavily influenced by Lynch (1960) and Piaget & Inhelder (1967), it simulates learning and problem solving while travelling in a large scale urban environment. It focusses on the cognitive map and divides knowledge into routes, topological street network, relative position of two places, dividing boundaries, and containing regions. The knowledge is represented through environmental descriptions and current positions controlled by a set of inference rules. A limitation of this model is that it only addresses part of the knowledge in the cognitive map and cannot provide information on issues like map-reading and the use of mental imagery to create a picture for the 'mind's eye' (Kuipers (1978)). Moreover TOUR is not based on the empirical research on spatial knowledge, cognitive maps, spatial orientation, or wayfinding (Gärling et al. (1994)).

Other cognitively based computer models that simulate learning and problem solving in spatial networks have been developed. Further information regarding these models can be found in Table 7.

5.2 Mathematical Models and Quantitative Measures

Cognitive and computer models of wayfinding have provided insight into how a cognitive map is formed, how routes are planned and how these plans are executed. While this research has provided insight on the human factors involved in wayfinding and shown the importance of environmental factors such as landmarks, it has not been able to provide designers and architects with tools to allow them to design spaces that minimises disorientation and confusion. For this reason, Braaksma et al. (1980) developed the visibility index as a measure of orientation. Measures such as these provide quantification for the 'goodness' or ease of wayfinding for a particular built environment, which can be used for the comparison of wayfinding between different built environments.

5.2.1 The Visibility Index (VI)

Using the idea that a person must first find, then orient themselves towards a destination through a direct sight line before being able to move towards it

(Gibson (1950)), the visibility index (VI) was proposed as an attempt to relate ease of wayfinding to the value of available sight lines in an environment (Braaksma et al. (1980)). A network of nodes and links were used to represent transpiration terminals. Nodes are activity centres or facilities where passengers are processed (for example check-in counters in an airport) or partake in discretionary activities (for example eating or shopping); links represent the sight lines from one activity centre to another. The network can also be represented, stored and manipulated as an adjacency matrix whose elements record the existence of sight lines through binary notation: a score of 1 is recorded when a target is seen either directly or through signs, and a zero is recorded when the target cannot be seen from a node.

By equating ease of wayfinding as a function of the existence of sight lines, the visibility index is the ratio of the number of sight lines, or links, between nodes in a terminal and the total number of sight lines that should exist within the terminal. It is expressed as $V = L_a/N(N-1)$ where V is the visibility index for the terminal, L_a is the number of links in the network, and N represents the number of nodes. This value can be expressed as a percentage to represent the visibility (and hence orientation and ease of wayfinding) across the possible links in a terminal. The visibility index for any subsystem in the terminal (V_s) and for an individual node (V_i) can also be calculated. The equations and associated terms of these measures, along with the other indices discussed in this section are shown in Table 8.

The visibility indices V, V_s and V_i are useful indicators of the ease of wayfinding in a particular terminal. Higher index values indicate easier wayfinding in the terminal, but a comparison of the visibility indices between different terminals requires the construction of a base matrix (Braaksma et al. (1980)).

A base matrix has a basic number of nodes which depend on the type of terminal being compared. For airports, 26 nodes were considered important (Braaksma et al. (1980)). The base matrix is populated with sight line data from the terminals being investigated using the same binary notation as the adjacency matrix. The visibility indices (V, V_s and V_i) can then be calculated for each terminal and comparisons between terminals undertaken.

The visibility index can be applied to evaluate the ease of wayfinding in transportation terminals in a number of situations. It can be used to evaluate a new or existing terminal layout, to examine *a priori* and *a posteriori* to changes in signage and layout to assess whether the changes had an impact on the ease of wayfinding for users and to evaluate ease of wayfinding for a terminal or parts of a terminal. By developing a base matrix, the VI of different terminals can be calculated and compared. Information about the size or complexity of terminals is not included due to the assumptions made during the construction of the base matrix.

Tosic & Babic (1984) extended the work by Braaksma et al. (1980) allow inter-terminal comparisons. In order to improve the VI measure, a matrix of visual connectivities (where the existence of connectivity between nodes be designated in a binary fashion and the remaining matrix elements stay empty) and a matrix of relevant connections (where connections, or links, in the network are classified as relevant or irrelevant) is constructed. The resulting visibility index, V_T, is a more realistic measure of human orientation or ease of wayfinding as it omits all irrelevant connections.

A further extension by Tosic & Babic (1984) produced a visibility index

(V_{Tw}) that placed a weighting on each node in the network based on the importance of the activities at those nodes. The process of classifying the importance of node activities is subjective since terminal owners may have different opinions to concessionaires, architects or designers. Primary activities (those that must be performed by passenger) are given a weighting of 1 and secondary activities (mainly services) are given a weighting between zero and 1.

Tosic & Babic (1984) also proposed a total visibility index for buildings with complex passenger flows (V_{TOT}). This measure uses passenger flow information from different parts of the terminal, as well as the total passenger flow in the building. See Table 8 for further details.

Dada & Wirasinghe (1999) extended the work by Tosic & Babic (1984) to include a factor for visual access, which is affected by the number of signs and level changes required to reach a destination. A visibility index for the whole terminal (V_D) and for each activity centre in the terminal (V_{Di}) can then be calculated (Table 8).

Comparisons of the visual index models has been undertaken by Lam et al. (2003), Tam & Lam (2004) and Churchill et al. (2008). Lam et al. (2003) used data from Hong Kong International Airport (HKIA) to compare the indices given by V, V_T and V_{Tw} and found that V, the measure proposed by Braaksma et al. (1980) gave the smallest result. The weighted model by Tosic & Babic (1984), V_{Tw}, gave the largest value, most likely due to the exclusion of irrelevant routes. The study of the HKIA departures level by Tam & Lam (2004) yielded the same results as Lam et al. (2003). Churchill et al. (2008) used Calgary International Airport (YYC) to compare the models by Tosic & Babic (1984) and Dada & Wirasinghe (1999). They found that the difference between the results from V_T and V_D can be largely attributed to signage. The inclusion of the visual access factor in the latter model broadened its range and acknowledged the importance of good signage. The authors argued that while the Dada & Wirasinghe (1999) model, V_D, requires more data, it is conceptually more sound.

5.2.2 Inter-connection Density (ICD)

Inter-connection density (ICD) is an objective measure of the physical environment and measures the complexity of a floor plan (O'Neill (1991b)). It is based on the density of interconnections between choice points in a building floor plan, and indicates the density of traversable paths between places in an environment. It is calculated as the ratio of the sum of all the links to a decision point with the number of deception points in the building and can be considered as the average number of links or corridors per decision point.

Increases in the ICD result in an increase in wayfinding difficulty due to the decrease in the accuracy of the cognitive map formed (O'Neill (1991b)). It also increases the mean time to find a destination, the average number of wrong terms and the average number of backtracking incidents. Incremental differences in ICD are shown to have significant impact on reported measures of the accuracy of the cognitive map and wayfinding performance. Through the ICD, it has been proposed that the topological complexity of a built environment is an important variable that has a large influence on the overall legibility of an environment.

A strength of the ICD is its ability to provide information about the effects of the physical environment on the mental image formed of the setting and actual wayfinding performance, all from a two-dimensional plan. This simple measure is one of the most popular space syntax methods used in the research of wayfinding.

5.2.3 Space Syntax

Space syntax is a set of analytic techniques that describe the relationship between space and society (Hillier et al. (1984)). By using graph-based techniques, it formulates the configurational properties of space and attempts to describe and analyse patterns of architectural space at the building and urban level, and the way in which spatial patterns are formed through buildings and cities (Hillier (2005)).

Space syntax analysis requires the space or layout being investigated to be broken into its constituent spaces using either a convex map, or an axial map. The convex map is generated by partitioning the layout into a set of fewest and fattest convex spaces. These are the largest units that can be fully perceived at one time within a building (Hillier et al. (1984), Peponis et al. (1990)). A convex space has all of its two dimensional extensions visible from each of its points, is the most elementary unit of analysis and represents the local constituents of a layout. The convex map can then be translated into a graph by denoting each convex space with a node and each accessible connection with an edge.

The axial, or linear, map is constructed by laying down the 'longest straight line' that passes through one convex space to another (Hillier et al. (1984)). The resulting network of intersecting lines is the axial map, which can also be converted into a graph where each line is represented by a node and each intersection representing an edge. The axial map captures the sense of movement through the building and represents the global constituents of a layout (Bafna (2003), Peponis et al. (1990)).

Once a layout has been broken into its constituent spaces, space syntax theory quantifies the way in which a convex space or axial line is connected to other respective spaces or lines by providing measures such as depth, integration, connectivity and intelligibility (Hillier et al. (1984, 1987)). Depth is the sum of the lines necessary in order to reach all the other nodes in the space and is the basic syntactic measure of distance. A connection between two axial lines is shallow or direct if only a few intervening lines have to be traversed when going from one to another. A space is integrated when all the other spaces of the building are relatively shallow from it. Highly integrated spaces require fewer changes in direction in order to move from that space to another. Integration measures the relative position of any space or axial line with respect to the overall building configuration. It can be calculated by analysing the graph that represents the number of changes in direction and depth of spaces that must be travelled from one space to all other spaces in the layout and is referred to as the RRA, or real relative asymmetry value. Connectivity is a local measure and is the number of other axial lines or spaces that are directly connected to any one line or space. Intelligibility refers to the entire system configuration and is measured as a correlation between global and local variables and is expressed by Pearson's Product Moment Coefficient, r. A strong correlation indicates that more of the global configuration of the space may be inferred directly from its local connections.

Space syntax provides tools and measures to make analytic definitions of the spatial structures (properties of layouts) that are involved with how people they locate and circulate themselves in buildings. Studies using space syntax in wayfinding and cognitive research have taken place. Peponis et al. (1990) found that correlations existed between measures of a building's spatial configuration and indicators of wayfinding performance. Haq & Zimring (2003) used axial map techniques to model the travel patterns of participants and found that over a period of time, travel patterns began to correlate strongly with 'integration' and other space syntax global measures which suggests that spatial learning adapts to the larger organisation characteristics of the environment. Kim & Penn (2004), also using axial map techniques, analysed residents' sketch maps of their neighbourhood and found that the sketch maps showed similar 'integration' values as the streets in the real environment. The result from this study suggests that the residents' spatial knowledge and the axial map capture similar environmental properties. Hölscher et al. (2010) observed the travel routes of novice and expert travellers in a complex building and observed that novices chose travel paths that were more visually connected and 'integrated' than the expert travellers who were more likely to take hidden routes. Finally, Haq (1999) found the existence of a relationship between the wayfinding use of axial lines and nodes and their space syntax integration values. He concluded that since wayfinding is an activity that is mediated by cognition, there is an indication that integration has a cognitive component.

Space syntax provides provides a diverse set of quantitative measures and indices for characterising spaces and buildings and provides potentially relevant information regarding route choice, spatial knowledge acquisition, orientation and disorientation, and aesthetic judgements, however it has its limitations. It underplays the significance of metrics such as distance and direction and overlooks the relevance of the overall shape and layout of the environment, as well as the importance of the shape and pattern of path layouts (Montello (2007)). Individual differences are ignored, as are the superficial aspects of an environment such surface colours, patterns and textures. Combining the environmental measures provided by space syntax with the well tested methods and measures of experimental psychology, makes it possible to gain a better understanding of the interplay between internal human processes and the external environment (Dara-Abrams et al. (2010)). However, the limitations of space syntax mean that other modelling techniques must be used in order fully understand the interplay between human factors and the environment that results in wayfinding.

6 Discussion

Wayfinding is the process of finding your way to a destination in a familiar or unfamiliar setting using cues given by the environment. The success of this process relies heavily on the interplay between human and environmental factors. Spatial orientation, cognitive mapping abilities, route strategies, language, culture, gender and biological factors are used to formulate plans and make decisions which are based on information about the characteristics of an environment obtained from paths, nodes, landmarks, districts, maps and signs. These decisions must be transformed into actions in order to reach a desired destination, and decision making and execution requires individuals to match the representation of the environment with the environment itself. While the need to understand the interplay between human and environmental factors necessary to facilitate wayfinding has been of interest to the field of cognitive and computer science, there are other reasons for investigating wayfinding.

These reasons, as discussed in Section 2, including the need for effective and efficient flow of people, are particularly important in the setting of transport terminals, particularly airports. In this setting, passengers can be nervous, time-constrained, come from different cultural backgrounds, are unfamiliar with the language used, are inexperienced in the travel process, and are in an unfamiliar environment. If a wayfinding system based on principles and research is in place in an airport, it may negate some of the negative aspects experienced by passengers. The system could be used to direct the flow of people through the airport terminal from one process centre to another; it would be able to provide the correct information and direction for disabled passengers to correctly navigate their way through the terminal; it would facilitate evacuation of the terminal in the event of an emergency; it would reduce the tangible costs associated with passengers being lost; and it could be used to reduce the frustration and stress of passengers through the correct placement of signs and information. This would in turn improve passenger satisfaction and experience. This improvement of course needs to be balanced with an airport operator's need to generate income from retail outlets. A balance is required between erecting the correct wayfinding facilities to allow successful wayfinding for passengers to get through the airport, and the wayfinding elements they use to navigate people towards retails outlets. As evidenced by this review, this balance can be informed by an understanding of the important human *and* environmental factors required in the complex process of wayfinding.

Cognitive and mathematical models have been proposed to understand this process and to determine which factors are most influential in wayfinding. Cognitive research has been able to define issues such as memory, cognitive mapping, spatial recognition and information processing and furthered the understanding of how the physical world is interpreted. It has provided insight into how a cognitive map is formed, how routes are planned and how these plans are executed. This has resulted in the development of cognitively based computation models that simulate a wayfinder moving through an environment in order to solve route planning tasks. These models, however are based heavily on the human aspects of wayfinding and lack the environmental aspects.

The mathematical models discussed in Section 5.2 provide a quantification measure of the ease of wayfinding in a built environment, and can be used to compare wayfinding between different environments. The visibility index (VI) provides a way to measure the ease of wayfinding in a built environment. The VI for a whole terminal, a subsystem of a terminal, or an individual node can be calculated by representing a transportation terminal as a network of nodes (activity centres) and links (lines of sight), Higher VIs indicate easier wayfinding and inter-terminal VI comparisons can also be made. The inclusion of node weightings, the number of signs needed to move from one node to another and the number of level changes required to reach a destination extended the original VI model. Another measure, the inter-connection density (ICD), evaluates the complexity of a floor plan based on the topological relations between choice points. Increases in ICD are associated with increases in the difficulty of wayfinding. These measures are purely on the environmental aspects of wayfinding and do not account for any human aspects involved in wayfinding.

Since an individual's human factors *and* the elements of the environment play such an important role in wayfinding, any model used to describe and understand wayfinding must include these factors. Space syntax, as discussed in Section 5.2.3, goes some of the way in doing this, however it ignores some important human and environmental factors. As evidenced by this review, what is currently missing in wayfinding research is a model with the ability to include the human and environmental factors involved in wayfinding and make a determination regarding which of these factors are the most important in this complex process.

Research into wayfinding has been able to provide the factors involved in wayfinding, and environments can be designed to make wayfinding easier. Recent technological developments contain the potential to make wayfinding easier. The increased use and availability of mobile devices and smart phones may be one way to do this. In the setting of an airport terminal, downloadable apps could be made available to terminal users. These apps could track the user's current position and show them the path to take to a destination such as toilets, the next activity centre, or their required gate. The use of mobile phones for airport and airline processes is not new: the International Air Transport Association's (IATA) e-travel vision for Bar Coded Boarding Passes (BCBP) allows passengers to use their mobile phones to gain access to flights using a scannable bar code that appears on their screens. A wayfinding app could be seen as a complimentary measure to initiatives such as the BCBP.

This paper has examined the ways in which wayfinding has been investigated by different perspectives and has provided a concise summary of research to date. It has made reference to the importance of wayfinding in the context of airports. From this examination, it is apparent that a holistic model that combines the human and environmental elements of wayfinding is vital in allowing the elucidation of the factors that have an impact on effective wayfinding.

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Figures

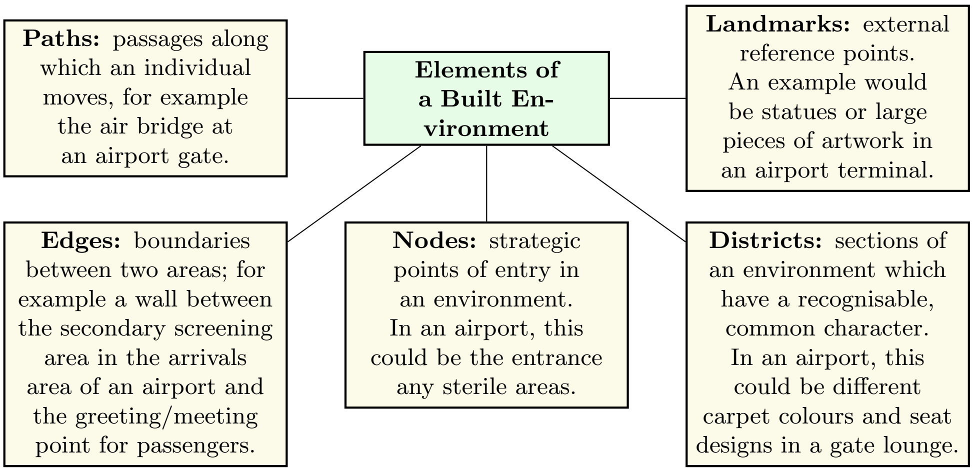

Figure 1: Elements of the built environment as classified by Lynch (1960), with examples of these elements as found in transportation hubs like airports.

Tables

Principle	Directive for Design and Guidelines
Equitable use	The design is useful and marketable to people with diverse abilities.
Flexibility in design	The design accommodates a wide range of individual preferences and abilities.
Simple and intuitive use	Use of the design is easy to understand, regardless of the user's experience knowledge, language skills or current concentration level.
Perceptible information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
Tolerance for error	The design minimises hazards and the adverse consequences of accidental or unintended actions.
Low physical effort	The design can be used efficiently and comfortably with a minimum of fatigue.
Size and space for approach and use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of users body size, posture or mobility.

Table 1: Principles of universal design which may be applied to evaluate existing designs, guide the design process and educate both designers and consumers about the characteristics of more usable products and environments (Connell et al. (1997)).

Cognitive Factor	**Definition**	**Reference**
Spatial Orientation	The ability to form a cognitive map.	Arthur & Passini (1992), Jesus (1994), Downs & Stea (1973), Tolman (1948)
Spatial Cognition	The internalised reflection of space.	Kitchin (1994)
Environmental Cognition	Awareness about environments.	Kitchin (1994)
Cogntive Mapping	Combination of spatial and environmental cognition that involves processes that allow people to acquire, code, store, recall and manipulate information about their spatial environment. A prelude to the ability to form map-like representations of the spatial environment.	Downs & Stea (1973), Ueberschaer (1971)
Cognitive Map	The end result of cognitive mapping. A person's internal representation, or mental construct, of the experienced world.	Downs & Stea (1973), Golledge & Gärling (2004)

Table 2: Definitions of common terms used in cognitive research.

Factor	**Action**	**Reference**
Route Selection	Path distance and travel time have been proven to be the most important factors in route choice. The shortest and most efficient route is chosen.	Dijkstra (1959), Seneviratne & Morrall (1985), Ueberschaer (1971)
	When there is no obvious correct route choice, the route that will minimise mental and physical effort is chosen.	Christenfeld (1995), Conroy Dalton (2003), Hochmair & Karlsson (2005), Hölscher et al. (2006), Seneviratne & Morrall (1985), Wiener & Mallot (2003), Wiener et al. (2004)
Route Strategies	Least angle: people minimise the cognitive effort needed in navigating and wayfinding by turning as late as possible. People try to maintain the track of the target direction throughout the journey.	Conroy Dalton (2003), Hochmair & Karlsson (2005)
	Initial segment: people focus disproportionately on the initial portions of a route and prefer routes with longer straight initial segments regardless of the length of the later portions of the route.	Bailenson et al. (2000)
	Fewest number of turns: routes with the least number of turns are chosen because each turn made allows for a potential risk of getting lost. Minimising the number of turns involved minimises the chance of getting lost. This strategy requires good knowledge of the environment or a map.	Bailenson et al. (2000), Seneviratne & Morrall (1985)
	Fine-to-course: people plan a route to the region containing the destination, and only once inside that region do they determine a specific route.	Wiener & Mallot (2003)

Table 3: Route selection choices and strategies used to find a way to a destination.

Factor	**Results**	**Reference**
Gender	Differences exist in the spatial navigation skills and spatial abilities of males and females.	Chai & Jacobs (2009), Jonasson (2005), Linn & Petersen (1985), Malinowski & Gillespie (2001), Tlauka et al. (2005)
	Men perform better in spatial activities in wayfinding.	Chen et al. (2009), Contreras et al. (2012), Lawton & Kallai (2002), Lawton (2010), Malinowski & Gillespie (2001)
	Men perform only slightly better than women in spatial visualisation tests.	Linn & Petersen (1985)
	Men are more accurate in navigating tasks when directional information is given.	Chai & Jacobs (2009), Lawton (2010), Levy et al. (2005), Postma et al. (2004)
	Men prefer and rely on distal cues (e.g. hill lines) to provide information on orientation and direction.	Barkley & Dye (2007), Chai & Jacobs (2009), Fortenbaugh et al. (2007)
	Men score significantly higher in mental rotation, spatial perception tests and dynamic spatial ability.	Cherney & Collaer (2005), Collaer & Hill (2006), Halpern & Tan (2001), Jonasson (2005), Lawton (2010), Linn & Petersen (1985), Silverman et al. (2007), Titze et al. (2008)
	Women show greater spatial anxiety than men. Higher anxiety has a negative impact on navigational ability and spatial performance.	Barkley & Dye (2007), Gabriel et al. (2011), Lawton & Kallai (2002), Malinowski & Gillespie (2001)
	Women prefer exact, pinpoint cues (e.g. landmarks) to identify a visual scene and form spatial orientation.	Barkley & Dye (2007), Chai & Jacobs (2009), Lawton (2010)
	Women have better object memory and object-location.	De Goede & Postma (2008), Lejbak et al. (2009), Levy et al. (2005), Postma et al. (2004)

	Women tend to adapt more easily to changing route instructions than men.	Anacta & Schwering (2010)
	Women perform better in object location tests.	Barkley & Dye (2007), Voyer et al. (2007)
Language and Culture	Cultural backgrounds are responsible for the differences in how space and spatial relations are conceived. Different languages structure experience differently, and people who speak different languages perceive and think about the world quite differently.	Whorf (1941)
	People who use a language with more differentiation perceive reality differently to people who use a language with less differentiation.	Carroll (1956), Frank (2009)
	Differences in vocabulary and terminology, geographical style, cultural meaning of terms, conversation style impact on cognitive mapping and spatial cognition.	Grice (1989), Frank (2009), Lawton & Kallai (2002), Montello (1995)
	People perform better at wayfinding tasks when they are given their instructions in a relative frame of reference. More stops and deviations were needed to find a destination when people were given instructions in the absolute reference frame.	Anacta & Schwering (2010)
	Different people prefer or respond to one or more of cardinal directions, clear route instructions, exact distances, or others prefer approximations based on landmarks.	Anacta & Schwering (2010)
Biological	Testosterone, or the exposure to testosterone, results in increased performance in spatial and navigational tasks.	Halpern & Tan (2001), Jonasson (2005), Lawton (2010)

	Performance in spatial tasks fluctuates across the menstrual cycle in women. Poorer performance occurs when women are in the midluteal phase of the menstrual cycle and estrogen levels are high.	Chiarello et al. (1989), Gabriel et al. (2011), Halpern & Tan (2001)
	More pronounced right hemisphere on males is attributed to better performance in spatial tasks.	McGlone (1980)

Table 4: Results of some cognitive studies investigating the impact of gender, language, culture and biological factors on spatial skills and performance and wayfinding.

Factor	Action	Reference
City Layout	Grid configurations of cities, or city block matrices are easier to comprehend.	Lynch (1960)
Landmarks	Landmarks make wayfinding easier. They signal where a crucial action should take place, help to locate another less visible landmark and confirm to a pedestrian that they are still on the right way. They provide important information at points in a route where changes in direction are likely to occur and contribute to creating a visual model of critical parts of an environment.	O'Neill (1991a), Richter (2007), Tom & Denis (2003)
	The placement of landmarks at decision points affect cognitive wayfinding strategies and facilitate orientation.	Lynch (1960), Richter (2007)
	For a landmark to be salient, it must contrast with the environment in either its attributes (colour, texture etc), status (e.g. a church or commercial building) or its spatial location with respect to other objects in the environment (e.g. in the middle of town).	Caduff & Timpf (2006)
	Landmarks should be used as the primary means of providing directions to pedestrians.	May et al. (2003)
Color and Light	Cool colours are calming and help people focus on visual and mental tasks. Cool colours can increase awareness and help direct people them to a destination. It has been shown that cool-colored walls are seen as more navigable.	Hidayetoglu et al. (2012), Stone (2003)

	Warm colours focus people outwards and increase their awareness. The use of warm colours allows people to more easily perceive the space and it has been shown that warm colours can be effectively used as landmarks for wayfinding purposes.	Hawes et al. (2012), Hidayetoglu et al. (2012), Stone (2003)
	Indoor lighting directly effects people's emotions, memory, perceptual-orientation and problem-solving abilities. Spaces with low brightness levels are perceived negatively compared to other brightness levels. Increases in the brightness level of a space positively correlated with positive perception of the space.	Hawes et al. (2012), Hidayetoglu et al. (2012), Knez & Kers (2000)
	The use of cool colours and high brightness levels help people be spatially orientated.	Hidayetoglu et al. (2012), Hygge & Knez (2001)
Maps	Maps are used to acquire spatial knowledge, especially survey representations which usually require a long time to acquire via route navigation alone.	Apelt (2008), Hölscher et al. (2007), Thorndyke & Hayes-Roth (1982)
	Map learning leads to superior performance only when aligned with the initial orientation of the map. The resulting representation is precise, yet inflexible.	Richardson et al. (1999)
	There is mixed evidence regarding the existence of a positive relationship between access to floor maps and a improved wayfinding performance and spatial learning in an unfamiliar building.	Hölscher et al. (2007)
Signage	Signage is used to compensate for complex floor plans in order to make wayfinding easier.	O'Neill (1991a)
	Signs placed at decision points improve wayfinding performance.	Best (1970)

	Direction signage has been shown to have the greatest effect on wayfinding and is relied upon heavily in order to make decisions regarding wayfinding.	Tzeng & Huang (2009)
	In some settings, signage enhances wayfinding and reduces confusion and stress, however in other cases it is ignored or found to be confusing.	Seidel (1982), O'Neill (1991a)
	Textual signage has been shown to be the more effective than graphical signage in reducing wayfinding errors such as wrong turns and backtracks. Graphic signage though has been shown to allow for a faster flow of people in a building.	O'Neill (1991a)

Table 5: A summary of research that has been undertaken on the environmental factors that impact on spatial orientation, cognition and wayfinding performance.

A map must be designed such that it:
1. Organizes the environment into clear spaces.
2. Shows all the elements such as paths, landmarks and districts of the area, but must ensure that it only includes important memorable connections so as not to overload the map with unimportant details.
3. Identifies the user's current position.
4. Orients the map to the user.
5. Ensures that any graphic communication used is unambiguous and any lettering used is proportional to the layout so that the map remains uncluttered.
6. Provides sufficient information to lead the use to the next map or directional sign.

Table 6: Elements of good map design (Apelt (2008)).

Computation Model	Model Description
ELMER (McCalla et al. (1982))	• Consists of three modules: *map* sends information to *planner* who develops a plan which is sent to the *executor* to carry out. • The executor module can modify the plan using knowledge of the environment. • When the plan is completed successfully, it is sent to the map module as a route which can be used with other routes and retrieved as and when the need arises. • The system learns from past experiences but cannot handle any catastrophic execution events such as a previously successful route being blocked.
SPAM: SPAtial Module (McDermott & Davis (1984))	• Positional knowledge (topological facts) and relational knowledge (such as relative position, orientations and scales of objects) are used to model route planning. • Relational knowledge coordinates are ‘fuzzy’, allowing for inferences about objects to be made, and for uncertainty in the position and orientation of the object. This allows for uncertainty in the object and provides a framework for data acquisition and assimilation when planning over uncertain domains. • A successfully completed plan is sent to the map module as a route and can be associated with other routes. • SPAM is unable to modify a plan if it finds that the original path is unexpectedly blocked, nor can it address any of the temporal issues associated with route planning (Slack & Miller (1987)).
NAVIGATOR Gopal et al. (1989)	• Combines information from contemporary psychological research and theory, elements of cognitive psychology and artificial intelligence to investigate effects of environmental variation and individual differences in learning. • Basic components of human information processing such as filtering, selecting and forgetting considered and used to investigate how environmental information is extracted and used. • Can be used to investigate wayfinding activities by newcomers to unfamiliar environments. • The model is criticised for its assumptions and simplifications of many aspects of cognitive structures and process.

TRAVELLER (Leiser & Zilbershatz (1989))	• Nodes represent different points in an environment and edges to represent the actions required to go from one node to another to describe a route as a sequence of edges and nodes. • Investigates how new knowledge about the external environment is integrated into the existing model. • Able to confirm the importance of nodes and landmarks in route finding, but was unable to provide insight into travel behaviour or confirm cognitive research about human processes.
PLAN: Prototype, Location and Associative Network (Chown et al. (1995))	• Attempts to unify the cognitive and perceptual aspects of wayfinding by using the views that an observer would see from different head angles at a single location. • Builds spatial cognitive knowledge in four stages: landmark identification, path selection, direction selection and environmental integration. • Different levels of spatial information acquisition can be considered due to the model's hierarchical nature. (Wong (2008)).

Table 7: A summary of some cognitively based computer models that simulate learning and problem solving in spatial networks.

Model	Equation	Terms
Braaksma et al. (1980)		
Visibility index for a terminal (V)	$V = \frac{L_a}{N(N-1)}$	L_a = number of links in the network N = number of nodes in the network
Visibility index for any subsystem in a terminal (V_s)	$V_s = \frac{L_s}{N_s(N_s-1)}$	L_s = number of links in the subsystem N_s = number of nodes in the subsystem
Visibility index for an individual node (V_i)	$V_i = \frac{L_t + L_f}{2(N-1)}$	L_t = number of links in the going to all other nodes L_f = number of nodes coming from all other nodes N = number of nodes in the network
Tosic & Babic (1984)		
Visibility index for a terminal (V_T)	$V_T = \frac{\sum_{i,j} c_{i,j}}{\sum_{i,j} r_{i,j}}$	$c_{i,j} = \begin{cases} 1, & \text{if node } j \text{ is visible from node } i \\ 0, & \text{otherwise.} \end{cases}$
		$r_{i,j} = \begin{cases} 1, & \text{if the connection between } i \text{ and } j \text{ is relevant} \\ 0, & \text{otherwise.} \end{cases}$
Visibility index for a terminal with weighted nodes (V_{Tw})	$V_{Tw} = \frac{\sum_{i,j} c_{i,j} w_j}{\sum_{i,j} r_{i,j}}$	$c_{i,j}$ and $r_{i,j}$ are as above w_j = weights for each secondary activity centre
Total visibility for buildings with complex passenger flows (V_{TOT})	$V_{TOT} = \sum_k V_k p_k$	V_k = the partial indices for individual passenger flows (departure, arrival, domestic, international, etc) p_k = proportion of passenger flow k = total passenger flow in the building
Dada & Wirasinghe (1999)		

Visibility index for a terminal (V_D)	$V_D = \dfrac{\sum_{i,j} c_{ij} k_{ij} w_j}{N \sum_{i,j}^{N} w_j}$	$c_{i,j} = \begin{cases} 1, & \text{if a direct connection with no level changes exists between node } i \text{ and } j \\ k_{ij}, & k_{ij} \text{ if a visual connection does not exist, but a connectivity is possible by signs.} \end{cases}$ k_{ij} = visual access factor $= \mathrm{e}^{-(0.01n+0.1L_c)}$, where $0 < k_{ij} < 1$, w_j = weight of activity centre j N = number of activity centres
Visibility index for each activity centre (V_{Di})	$V_{Di} = \dfrac{\sum_{i=1}^{N} c_{ij} k_{ij} w_j + \sum_{j=1}^{N} c_{ij} k_{ij} w_j}{2N}$	$c_{i,j}$, $k_{i,j}, w_j$ and N are as above.

Table 8: The Visibility Index was initially proposed by Braaksma et al. (1980) as an attempt to relate ease of wayfinding to the value of available sight lines in an environment. The original model has been extended to include weightings for activity centres and the include the impact of level changes and signage.

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