CHAPTER NINE
Conclusions and Future Research

As a fundamental spatial activity in people's daily lives, wayfinding is an interactive behaviour between people and their environments. The acquisition of spatial knowledge and performance of spatial tasks such as wayfinding involves interactions between people and their environments. Interaction between humans and the environment has been researched from cognitive aspects over the decades and various conceptual models or schema have been established to understand how people structure and develop an inner representation through recording and processing information based on their perception of the real-world and inferences about it. There has been rather less focus upon studying overt behaviour during the actual process of wayfinding (Chapter 3). On the other hand, the rapid development of wireless mobile information and communication technologies is providing new ways to deliver spatial information to the individual on the move. Thus there is every possibility for spatial information to be acquired by individuals using their wireless mobile devices in real-time, at any location. Much of this information could be used to assist wayfinding, be interactive and have the content dynamically refreshed with updates. These developments are pertinent to the study of people's spatial abilities, and the ways in which they acquire spatial information and develop spatial knowledge. Yet to date, the role of new technologies has not been assimilated into wayfinding research. This thesis has highlighted the implications and articulates the questions and challenges arising from the impacts of NICTs (Chapter 2) for wayfinding and spatial information research. It seems axiomatic that these new ways of accessing spatial information are affecting the nature of human wayfinding, but as yet we understand rather little about these developments.

In this research, urban wayfinding has been studied from a new perspective. The technological element has been included into the wayfinding research, both as a new aspect of interaction between people and a source of spatial information, and as mediation between people and the environment. Wireless mobile devices as sources of spatial information have a pivotal role. Thus by studying the details of these interactions and spatial information transactions, we can gain an understanding and insight into the level of information that is sufficient to individual needs, the desired types of information, frequency of use and preferred modes of communication for completing wayfinding tasks. This understanding can be set within the context of an individual's spatial ability. Moreover, the actions taken in response to the knowledge gained from the acquired spatial information can also be studied in relation to the different spatial configurations of the environment.

To restate the aim of this research: it has been to investigate the real-time interactions and information transactions between individuals, their mobile devices and urban environments during pedestrian wayfinding activities.

In this research, a dynamic interaction model (Chapter 5) has been devised at a conceptual level with an explicit focus on the overt interactions and spatial information transactions between individuals, mobile devices and urban environments. This conceptual model provides the framework for the research within which many aspects of the interactions, spatial information acquisition, and individual wayfinding behaviour can be studied. The conceptual model differs from many existing human-environment interaction models because the technological element, in the form of wireless mobile devices, has been brought into the interaction between people and their environments. Furthermore, the mobile device is considered as an information source with which individuals actively interact during spatial wayfinding tasks.

In order to implement aspects of the conceptual model, a novel methodological approach (Chapter 5) has been developed with the focus on collecting and analysing data from real-time spatial information transactions and overt interaction behaviour during spatial activities such as wayfinding. The approach consisted of experiments in a VR-based test environment, combined with questionnaires and debriefing interviews. This approach provided the means to collect a rich data set regarding individuals, their spatial information transactions and usage, overt spatial behaviour and interactions with the environment. It could be used to overcome many of the challenges faced in studying the actual process in real-time, whilst avoiding the shortcomings that result when such measurements are carried out after the wayfinding activities have ceased. Furthermore, this approach could be deployed in the study of needs and uses of spatial information in mobile situations with the emphasis on the individual user.

For this research, a VR-based test environment has been designed and created. It provides realistic stable urban settings in which individuals can 'walk' and access spatial information using their mobile devices in order to complete wayfinding tasks. During these tasks users can interact with the mobile device to obtain different types of spatial information, and at the same time the details of these transactions can be observed and recorded. The test environment comprises of three main parts: two contrasting VR urban models with their own distinctive layouts and mix of architectures, a mobile device (a PDA) providing simulated LBS applications and multi-source data collection software for recording individual behaviour and interactions with the mobile device. Such a test environment could also be deployed for a wide range of investigations in the design and use of LBS applications, and other mobile technologies, with a user focus.

The validity of wayfinding experiments in the VR-based test environments has been assured from three aspects. Firstly, the commonality of wayfinding strategies and features used by the participants in the VR test environment and in the real-world was confirmed through the two consistent sets of feedback following wayfinding experiments in two different urban settings. The results show that all participants reported that they used a similar approach and features in the VR urban environments during the experiments as they would do in the real world. Secondly, the VR-based test environments were created based on real urban areas from the dual perspective of geometry (layout) and characteristics such as the arrangement of buildings and the realism of the façades. This was to provide a consistently realistic setting for the experiments. Thirdly, is the control of the alternating sequencing in which participants experienced the two contrasting urban settings. The findings show that there was no consistent significant differences in the setting sequence amongst the participants in terms of their wayfinding behaviour as measured by distance travelled, time taken to complete, frequency of PDA spatial information access, time spent consulting PDA for the information and task planning times. These findings suggest that all participants exhibited consistent behaviour in completing wayfinding tasks and in using spatial information via the PDA. This is a positive sign that the data collected and analysed reflects participants' unaltered abilities during the wayfinding experiments in both test settings. Finally it should be reiterated that no participant had any prior knowledge of these areas. For these reasons, the experiments are considered to have validity in respect of their generalisable outcomes.

A series of detailed empirical wayfinding experiments concerning geographically extensive areas have been carried out using this methodology. The empirical data on interactions and information transactions thus generated have allowed a number of aspects of spatial information usage and wayfinding behaviour to be investigated in this research. Not only has every movement of the individual been tracked and their position plotted, but the frequency of spatial information access, the type of information accessed, when and where, and the time spent studying the information have all been quantified and analysed. The data make possible the investigation of wayfinding behaviour as expressed in route choice, distance travelled, time taken to complete, frequency of being lost/confused in the two contrasting urban settings. The data also enable the investigation of spatial information usage to be carried out when expressed as frequency of access, location of access, time spent and types of information consulted. In this respect, the conceptual model and the methodology used in its implementation have shown their advantages, not only at a theoretical level but also being applied empirically.

To reiterate for this discussion, the term 'spatial information usage' in this research refers to the situation where the spatial information is accessed and studied via a mobile device at real-time during wayfinding activities.

One aspect investigated in this research is the patterns of individual spatial information usage in assisting wayfinding. A set of variables have been elicited from the empirical data for describing the real-time usage of spatial information, including the frequency and time spent consulting the PDA for different types of spatial information, along with geographical position. Four distinct groups of individuals have been identified through the analysis of these variables (§8.6). Each of these four groups has marked differences in terms of their pattern of access and usage of spatial information via the PDA. These differences are statistically significant. These groups have been labelled as IN-G1 to IN-G4, where:

- Group IN-G1 with a preference for route information (sequential instructions).
- Group IN-G2 with a preference for maps, particularly more detailed localised map information.
- Group IN-G3 with mixed mode information, that is, either having an equal tendency to use route and map information or show greater flexibility in matching choice of information to the specific instances of spatial decision-making.
- Group IN-G4 with a strong preference for overview maps providing a more generalised spatial layout.

This grouping indicates that there are clear patterns of preferences in using different types of spatial information in wayfinding. These four groups are not just identifiable by their preference for particular types of spatial information, but also show discernable patterns in their temporal and spatial behaviour during wayfinding.

Whereas the preferences for particular types of information can be identified, the patterns of spatio-temporal usage also reveal that there are different but consistent strategies employed by individuals which reflect on the behaviour of the groups. Thus:

- For Group IN-G1, there is consistent reference to route information during the wayfinding tasks. However, where individuals encounter perceived difficulties or uncertainty either for planning the route or making choices at decision points, overview and detailed maps would be used with route information.
- For Group IN-G2, there is a pattern of using overview maps in conjunction with detailed maps for the planning of routes (at the start) but that all other information

along the route is acquired from detailed maps that provide localised information.

- For Group IN-G3, there is an alternation in using different types of information in different situations and settings. It appears that these individuals choose whatever suites their purpose in response to the surrounding environment.
- For Group IN-G4, overview maps are the dominant source of spatial information, with only very occasional use of alternative types of information. Individuals in this group are characterised by high frequency of spatial information access.

Moreover, the study indicates that the strategies used are consistent between the two contrasting urban settings. However the different urban settings did appear have an influence on the information usage strategies for Group IN-G3 as a consequence of their flexibility or willingness to change their information use in response to the changing situation.

From position/time data and PDA usage data, this study has identified a distinct period of higher spatial information access at the start of wayfinding tasks coupled with time spent in consulting and assimilating the information. This period is identified in this research as planning time. The planning time variable shows further differences between the groups and is an important aspect of their wayfinding strategies. Thus:

- For Group IN-G1, there is a tendency to take less time in planning the task more concentrating on the procedural route information and some detailed local layout that allows them to start quickly. Access of spatial information is more intensive along the routes as more information is required. This suggests a lack of configurational knowledge gained during task planning.
- For Group IN-G2, there is more time spent on planning tasks with some reference to overview maps but moving to detailed maps for local layout. Tasks tend to be planned sequentially with planning time equally distributed at the starting points of each successive task. This also suggests that the configurational knowledge gained is not spatially extensive but is locally focused.
- For Group IN-G3, there is time spent planning, however, overall there is a tendency to treat start points for tasks equally with decision points (such as road junctions) along the route.
- For Group IN-G4, there is considerable time spent on planning tasks with decreasing planning time used on successive tasks. This indicates that individuals within this group develop configurational knowledge of the area from their experience of the wayfinding.

Furthermore, complex settings and locations with more challenging spatial layouts tend to have more of an effect on individuals in Groups IN-G1 and IN-G3 in as much as they increase the frequency of spatial information access and change the type of information being accessed.

Another indication of differences between these groups has been evidenced through the sketch maps that capture their recall of spatial knowledge gained during the wayfinding tasks. Thus the individuals in Groups IN-G1 and IN-G2 do not seem to develop well structured configurational knowledge of the whole area. Recall of spatial knowledge and its representation as a sketch map can have its shortcomings (§3.4) but does nevertheless appear to be reflect self-assessed spatial ability. However, as identified in this research, self-assessed spatial ability does not appear to be the main determinant of patterns of spatial information usage strategies in wayfinding.

This new typology of spatial information usage groups has been shown to reflect a number of characteristics of wayfinding behaviour. These groups can be applied to a broader range of studies concerning the spatial information needs of individuals on the move. The four Groups have been further studied in relation to self-assessed spatial ability groups.

From the self-assessed questionnaires administered in this study, three different self-assessed spatial ability groups have been identified (§8.2) based on existing theoretical considerations. These three groups, SA-G1 to SA-G3 reflect low, intermediate and high self-assessed spatial ability respectively. This indicates that individual spatial ability may not be as clear cut as the binary divide of 'good' versus 'poor' ability as has previously been suggested.

The three SA Groups have been studied in relation to their wayfinding behaviour and in terms of their spatial information usage. The analysis indicates that the individuals with high self-assessed spatial ability (SA-G3) are more likely to familiarise themselves and study the spatial information from the mobile device (PDA) in the early stages of wayfinding. By contrast those individuals with low self-assessed spatial ability (SA-G1) are less likely to behave in this manner but tend to access information more frequently along the routes taken. Individuals in Group SA-G3 seem to have exercised more diversity in their route choices. Despite broad apparent similarities between SA and IN Groups, the cross tabulation of these two types of groups (§8.6) show that SA Groups are a poor predictor of preferences for spatial information usage as expressed in the IN Groups. Thus although self-assessed spatial ability groups give an indication of people's ability in respect of completing wayfinding tasks, they are not fully reflect the pattern of spatial information usage for assisting such wayfinding. This would suggest that spatial ability and, in particular, people's spatial information preferences are better determined through real-time data collection of wayfinding activities.

In this regard, measures of spatial information usage should be included as an integral indicator of individual spatial ability.

From the perspective of spatial knowledge acquisition discussed in §3.3, there are deemed to be three defined types of spatial knowledge: landmark, route and configurational knowledge. The groups based on spatial information usage (IN Groups) have preferences for route information, overview (synoptic) map information and detailed (localised) map information. In the usage of this information it is suggested that landmark are embedded and acting as part of route knowledge and configurational knowledge. Whilst the information in a detailed map may be considered as configurational, the evidence of this research is that such maps do not confer configurational knowledge to a great extent as they tend to represent only localised collections of landmarks.

Also from the self-assessed questionnaire, participants could be identified according to their tendency for route/landmark/map thinking. This research has shown that individuals with a tendency for route-orientated thinking also expressed a tendency for landmark-orientated thinking. The same was true of individuals with self-assessed map-orientated thinking. This further indicates that landmarks should be considered as an important element in all forms of spatial thinking.

Another aspect of this investigation has been the influence of urban morphology on individual wayfinding behaviour and spatial information usage. The attributes of the environment can have an important influence on wayfinding behaviour, and the VR-based approach has allowed such influences to be investigated in a systematic manner. In this research, two contrasting urban models with their own distinctive layouts and mix of architectures were used for the wayfinding experiments. Firstly, the effect of urban morphology on individual wayfinding behaviour has been analysed in terms of distance travelled, time taken to complete, time-distance relationships and route choices. There is a strong indication from these variables that the characteristics of spatial locations do have an influence on wayfinding behaviour. Also exhibited are the differences in wayfinding behaviour for each individual route. These differences can be quite marked (e.g. §8.4.4) and appears to vary according to the perceived complexity of each wayfinding task. Secondly, the effect of urban morphology on behaviour has been studied in terms of spatial information usage in wayfinding and found to have an influence on how spatial information is used for wayfinding. Significant differences were found between the two different urban settings in respect of the task planning time and the time spent on spatial information usage. Although the frequency of information access is higher in what would be considered the more challenging setting (U2), it is not statistically significant. The study also suggests that spatial layout and environment along the route do have an influence on frequency of PDA access and usage. Moreover, the study suggests that differences in urban layout seem to influence the pattern of information usage such as switching between different types of information. This is further supported by the patterns of spatial distribution of spatial information usage via the mobile device (§8.7).

Whilst this study has developed a number of important conclusions, a number of limitations to the study can be identified. Firstly, this study could have benefited from a larger sample. The funding obtained for the use of the VR facilities was limited to 30 participants. Three participants could not complete the experiments due to motion sickness. At an overall aggregate level, 27 participants have been sufficient for non-parametric statistical inference. However, at group level, the samples have sometimes been too small to statistically verify effects. Novel usage of a PDA for wayfinding and VR-based test environments may have been a distraction to participants. However, the findings would indicate that the experiments measured stable behaviour and does not appear to have been an effect from the feedback of the participants. For the urban models used in the VR-based test environments, there are no moving objects such as people, animals and vehicles. Whilst this may be construed as being artificial, it results in very little distraction during the wayfinding. One purpose of the VR test environments was to limit any confounding distractions that might otherwise occur is real world situations. It provides more a consistent setting for studying specific factors. VR does, however, have the drawback in that it can induce motion sickness. Finally, the methodology resulted in such a rich empirical data set, that it has not been possible to analyse all aspects within this thesis (but see future research below).

Whilst this research has achieved its aims and has answered a number of questions on the way spatial information, delivered to a mobile device, is used during pedestrian wayfinding, new questions have been provoked by these outcomes. The investigator has already received confirmation of an ESRC post-doctoral fellowship in order to explore these. Firstly, as intimated above, the volume of data generated by the methodology could not be analysed in all its aspects within the confines of this PhD thesis. Given space-time data on spatial information access, and the classification of preference groups already achieved, is it possible to develop a predictive model (either Markovian or Bayesian) of spatial information access? The results from this could result in some form of intelligent agent modelling. The VR urban settings could be enhanced with, for example, trees and vehicles (stationary and moving) as well as even people and used to conduct further experiments. Thus wayfinding and spatial information access behaviours could be studied for a broader range of age groups and for groups from different socio-economic and cultural backgrounds. Changes to building types, particularly height, within the same road geometry would allow investigation of any 3-D effect of urban morphology on wayfinding and spatial information usage. By changing certain parameters within the test settings it would be further possible to investigate the effects of day and night on individual wayfinding. Finally, whilst the current research has focused on the use of spatial information as text, voice and maps, an extended range of formats for spatial information as might be offered by multi-media could be studied.

This thesis has been a beginning, not an end.

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