CHAPTER FIVE
Conceptual Model and Methodology

As discussed in Chapter 2, the rapid development of mobile telecommunication technologies and the foreseeable usage of LBS applications pose new challenges and research questions for geographical information science and research into wayfinding. On the other hand, while the changing aspects of new technologies can enable researchers to explore different approaches, such as how a mobile device can be used for assisting people's wayfinding, they can also be used to collect data on the way in which people use spatial information (which will be discussed in this Chapter). Virtual reality, as discussed in Chapter 4, is used in this research for overcoming some of the methodological challenges for studying individual interactions with mobile technologies and environments in real-time. The extensive literature reviewed in Chapter 3, has identified the lack of research into the technological dimension to the interaction of individuals with their environments; to date there has been little research that explicitly focuses on the real-time interactions and spatial information transactions. Therefore, in this Chapter, a conceptual model is proposed which brings into focus the interaction and spatial information transactions between three main elements: individuals, mobile devices and environments. Challenges in studying such interactions and information transactions will be discussed and a novel methodological approach which has been developed for this study is presented. The details of implementation will be discussed in Chapter 6.

5.1 An interactive conceptual model

As discussed in Chapter 3, there has been considerable research into the processes of human-environment interaction, and in particular the role of spatial cognition, that is, the acquisition, storage and use of spatial knowledge in determining spatial behaviour. Since the 1960s there have been numerous conceptual models which have sought to embody theoretical understandings of the processes of such interactions in geographical space. These models have evolved considerably in their remit and complexity. Yet the principal focus has remained fixed upon two main elements: human beings and their innate qualities, and the environment as perceived and socially constructed. However, modern information and communication technologies increasingly act as a mediator between humans and their environments. Consequently there is a fundamental need to include this new aspect into the research. Moreover, given the short-term dynamics of many interactions there is a need to study and understand real-time processes which in turn necessitates being able to capture the actual dynamics taking place in real time.

Considering further the technological element, as discussed in Chapter 2, one of the main applications of fast developing mobile technologies is LBS, that is, the provision of location aware and context aware information which can be used to assist people in various wayfinding activities. Many applications aim to deliver spatial and spatially-related information to individuals who increasingly require more relevant and timely information via their mobile devices in order to perform various tasks. This shift from generic to user-centred mapping is one of the important challenges currently facing geographic information science (Longley *et al.*, 2001, Chapter 21). A related challenge concerns people's use of mobile technologies to access spatial information for their spatial activities in real-time, at any location. For example, in the applications of LBS that entail navigation, instructions could be given to people by means of maps, spoken word and/or text. It is envisaged that landmarks, points of interest and key features of neighbourhood environments will be provided as spatial cues via LBS. Yet there has been little research into understanding the way in which such spatial information services, via a mobile device in real-time, might be used at group- and individual-levels. Whilst interactivity between a mobile computing device and its user has been studied, the focus has been on the usability of devices with a clear emphasis on the design and implementation of systems with evaluation in laboratory settings. In such studies the surrounding environment is under-represented with limited attempt to accommodate the spatial environment on the interactions studied (§2.3.2). Few studies have explicitly focused on the dynamic interaction between individuals, mobile technologies and their surrounding environments.

In this research, a conceptual interaction model is proposed, bringing together the individual, mobile devices and environments as three elements and putting the focus explicitly on the interaction and spatial information transactions between them (Figure 5.1). Individuals, as one of the elements of the model, can access and acquire spatial information through a mobile device whilst acting and moving within the environment. They can also gain information directly from the environment. Individuals have been shown to have differences in terms of spatial ability, acquired knowledge and their social and cultural backgrounds. Mobile devices, as the technological element, act as information sources. In LBS applications, the mobile device is the medium by which information and services, tailored to the current or some projected location within the environment, are delivered to the individual. The environmental element can be viewed as including physical, socio-economic and cultural aspects (Gollege and Stimson, 1997, also seen Figure 3.1). The environment in which individuals act also identifies both spatial extent and context in terms of the various situations encountered.

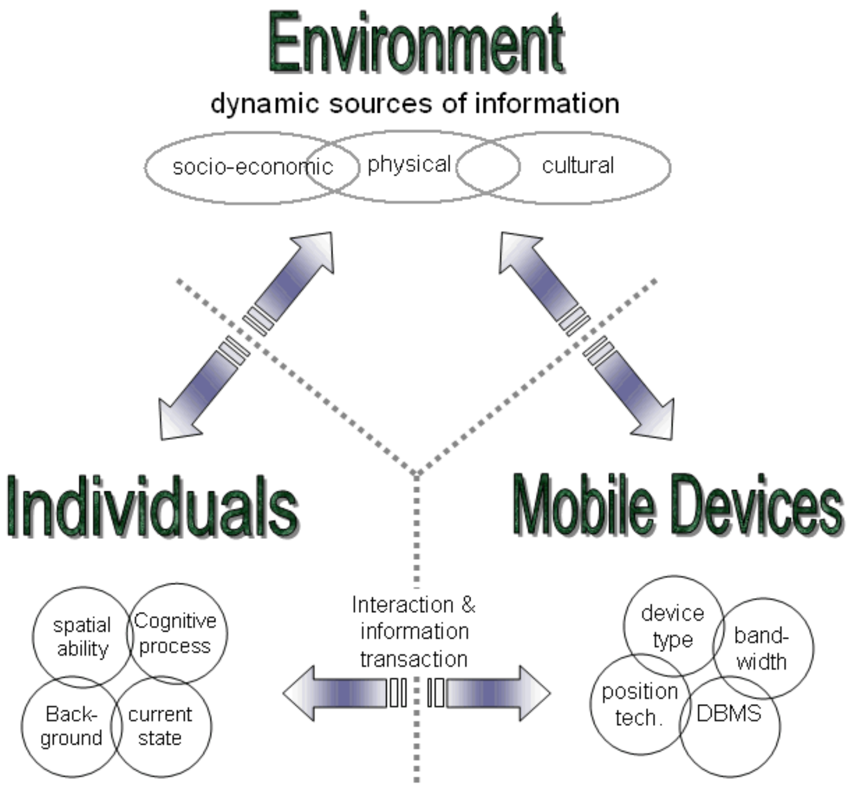

Figure 5.1 The proposed dynamic interaction model.

This dynamic interaction model explicitly places an emphasis upon overt interactions between individuals, environments and mobile technologies, and focuses on spatial information transactions. Rather than considering the complex cognitive processes carried out internally when individuals encounter environments, this conceptual model takes a different approach to investigate real-time, overt interaction. Instead of looking at individual elements or individually paired interactions, the model proposes that all three elements and their interactions need to be considered in their totality. Furthermore, in order to reach an appropriate level of understanding, the model requires real-time interactions and spatial information transactions to be studied. Taking the scenario of completing wayfinding tasks, individuals gain information about the environment from its distinctive physical features and on-going activities. The environment itself can be a dynamic source of information. When individuals are on the move, the information delivered via LBS-enabled mobile devices can be updated depending on their specific location. Individuals can request information through their mobile device at any time they require assistance in completing their wayfinding task.

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 elements of the environment – such as layout and point of choice.

In this research, in order to study the real-time interactions and spatial information transactions of this conceptual model, a specific context of pedestrian urban wayfinding using a mobile device has been implemented. The facility for real-time data capture creates a number of methodological challenges, because the information transaction between environment and mobile devices can be both real-time and dynamic. The information regarding geographical locations can be constantly refreshed according to changes at specific locations. Furthermore, information in mobile devices such as maps and instructions can also correspond to and be updated with reference to changing situations which might either be predictable factors such as day and night, or largely unpredictable factors such as traffic situation. In order to make the experiments tractable within the time available for the research, dynamic information transactions between the environment and mobile devices were not included in this research, and therefore are assumed to be constant. The focus was therefore on studying the real-time interactions and spatial information transactions between the individual, the environment and their mobile device.

5.2 Methodology

There has been a range of methods established and adopted to measure individual spatial ability, studying how people acquire spatial information and develop spatial knowledge. These are often used to understand people's inner representation of the environment, which is regarded as an important aspect of wayfinding research. As discussed in Chapter 3, these methods include:

- Self-reporting (self-rating) questionnaires.
- Tasks based on estimating distance and direction (in order to measure people's spatial knowledge of locations) using various methods of measurement. Usually these are uni-dimensional, measuring a single element rather than the whole configuration of an area. Although the single elements can be combined to measure the whole, the knowledge gained is constructed afterwards.

- Sketch maps drawn of an area in order to understand people's configurational knowledge about the area and of the locations of objects in relation to each other.
- Completing tasks such as retracing a route, remembering landmarks and routes taken.

These methods are generally used to investigate people's cognitive mapping aspects of wayfinding. However, there are issues of validity and reliability of these measures, as little research has been carried out to assess them (Kitchin and Blades, 2002). Furthermore, such data and measurements taken in a static situation after actually carrying out spatial tasks are likely to be influenced by a number of confounding factors such as different levels of individual knowledge and skills to perform such techniques, the ability to remember, willingness/patience to complete the measurement tasks and *ex post facto* rationale. However, the challenge of capturing the actual process in real-time still remains, since although it is possible to measure various manifestations of spatial knowledge and to measure aspects of how people acquire and learn spatial information, many of these methods attempt measurement after the activities of the wayfinding tasks have ceased. Apart from the obvious difficulty of making measurements in dynamic, mobile situations, there is also the issue of the extent to which spatial information has practical use (Frank, 2003).

As discussed in the previous Section, the proposed conceptual model focuses on exploring interactions and spatial information transactions between individuals, mobile devices and environments (Figure 5.1). The approach for implementing such a conceptual model put its emphasis upon gaining insight into the actual process. There are, however, a number of implementation challenges. To begin with, a real-world environment usually encompasses a larger geographical area for movement compared with a laboratory- or desktop-based situation. A real-world environment is difficult to control and can easily confound different aspects of user behaviour and interactions. For example, a real urban environment may vary during the time period that experiments are being conducted, in terms of weather conditions, seasonality of vegetation, busyness and so forth. Thus the seemingly infinite complexity of the real world is likely to provide interrupting and disrupting stimuli that become a challenge in the conduct of controlled studies. In addition, the information provided through mobile devices should be available on demand for assisting individuals to complete tasks. However, such applications are not yet widely used and it may be difficult for some individuals to understand their usefulness in relation to a full range of personal information requirements. There are also practical issues of safety and the ethics of carrying out experiments in the street with traffic and other hazards. Thus many, current methods have severe limitations and present difficulties for capturing interactive behavioural data pertaining to spatial information transactions by mobile individuals.

In this research, a different methodological approach has been established and implemented, with the focus on collecting and analysing data from real-time information transactions and overt interaction behaviour. The approach consisted of experiments in a VR-based test environment, combined with questionnaires and debriefing interviews. For the experiments, a multi-source data collection method was devised with a mix of automatic and semi-automatic data recording programmes. The experiments were set up with the aim of simulating real world wayfinding scenarios in an immersive VR-based test environment. The multi-source data collection method aimed to capture data on information transactions and overt behaviour in real-time. The conventional questionnaires conducted before and after wayfinding experiments were used to gain a range of information about each participant, their feedback and the knowledge that they felt they had gained. Taken together, the overall approach provides a range of data on individual spatial abilities, spatial information acquired, spatial locations, task performance and overt interaction behaviour. Such data could then be integrated and analysed for investigating spatial information transactions and the interaction between the three main elements: individuals, mobile devices and environment. These details of the methodology are now discussed in relation to Figure 5.2.

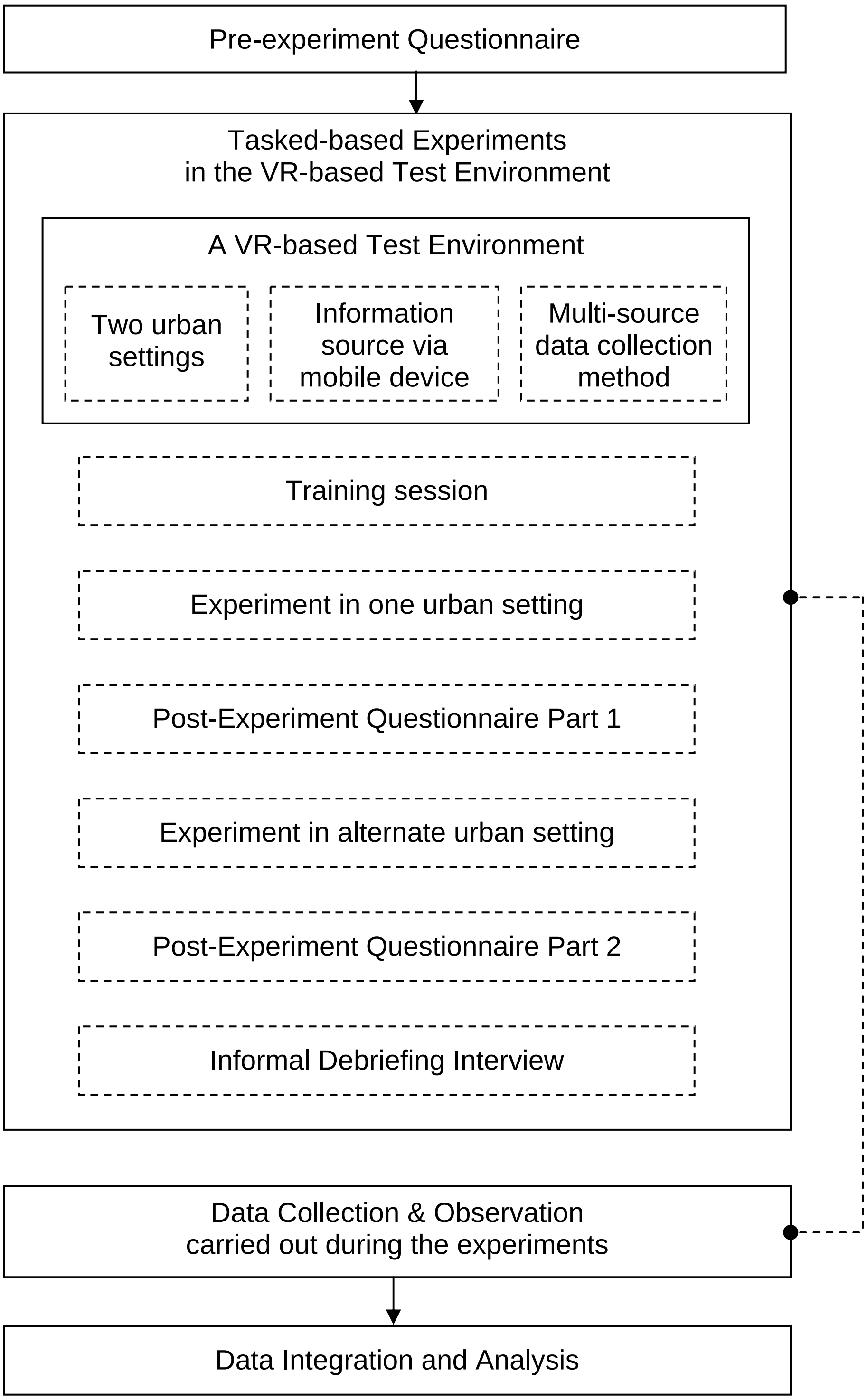

Figure 5.2 The elements of the methodology.

The main objective of setting up a pre-experiment questionnaire was to gain understanding of individual spatial ability, and their familiarity in using spatially enabling technologies. People's estimation of their sense of direction is believed to reflect their abilities to comprehend surrounding environments, to orientate themselves and to navigate: "A sense of direction is also derived from the perception of the known environment within which people move" (Gibson, 1979). Thus, self-reporting (also referred to as self-rating) questionnaires have been used to gauge participant general spatial ability and to provide indicators of ability to perform spatial tasks such as wayfinding. Such tools typically comprise a number of questions aimed at rating individual 'sense of direction' and rating their ability to perform various tasks. Kozlowski and Bryant (1977) consider that a sense of direction is an ability or trait that people can reliably identify as characteristics that they possess to a greater or lesser degree. A number of studies have demonstrated that people's self-reported measures of their sense of direction and spatial ability is a valid indication of their ability in wayfinding in large-scale environments (Montello, *et al.*, 1999; Hegarty *et al.,* 2002; Cornell *et al.* 2003). In this research, a questionnaire was proposed to be applied to reveal individual spatial ability, including questions relating to sense of direction, general spatial ability and spatial anxieties. The construction of this questionnaire drew on the previous research mentioned above, and the detailed design of the questionnaire is discussed in Chapter 6. In addition, an intention of this questionnaire was also to collect data on people's self-reported tendency for landmark-, route- or survey-centred thinking (Pazzaglia and de Beni, 2001). These were discussed in Chapter 3 as widely recognised types of spatial knowledge: landmark, route and configurational knowledge. The data collected from the questionnaire could, therefore, indicate the differences between individuals in terms of their self-assessed spatial abilities. The data could then be analysed with the real time data collected during the wayfinding experiments. Also included in the questionnaire were a number of questions on the individual usage of related technologies, such as mobile phones, PDA, the Internet and different forms of virtual realities. The purpose of setting up these questions was to identify variations amongst the selected participants in terms of familiarity with technologies. If different levels of the familiarity were to be reported amongst participants, their influence on the outcomes of the wayfinding experiments might then need to be considered.

An immersive VR-based test environment was proposed for carrying out the simulated real world wayfinding scenarios, aimed at offering a stable setting within which to study interactions and spatial information transactions at an individual level. The main focus of the test environment was to provide realistic yet controlled environmental settings in which individuals could access information through a mobile device in order to assist themselves in completing tasks, and where information transactions and user interaction could also be observed and recorded for analysis. This test environment comprised of Virtual Reality (VR) models of urban settings, a mobile device as information source and a multi-source data collection method for recording data on movement, information usage and actions. VR has several important characteristics useful as creating a test environment. First of all, when setting up a test environment in VR, it can be purpose built. For instance, different types of road network layout can be created and special landmark buildings can be located for evaluating how people find their way in response to these features. Another important feature of VR is that it can provide a controlled test scenario for experiments. Interference factors (deemed extraneous to the experiment) that might affect the experiment in the real world can be removed. In researching wayfinding, the experiments might need to be conducted over several months, and to involve a number of participants. A real urban environment may change during this time period, in terms of, for example, lighting conditions, weather conditions and effects of seasonality. The lack of control over extraneous factors may bias the resulting data and confound analysis. The VR-based test environment provides a consistent setting that is equally unfamiliar to each participant who is requested to undertake clearly defined tasks. Any interference which is not specified within the remit of the investigation can therefore be avoided. The behaviour of participants can then be analysed on a much more equivalent basis. In addition, a VR-based test environment allows experiments to be monitored more easily and intensively. Participant movements can be recorded by the VR tracking system. Participant actions and overt behaviour can be closely observed either directly by the investigator or through automated means – which would be much more challenging in a real environment.

Figure 5.3 illustrates a range of test environments in relation to key dimensions of realism of the environment, interaction with the environment and control of the experiments (Mallot *et al.*, 2002). The real world (RW), construed as an experimental environment, has the advantage of being 'real' and allowing participants a high degree of interaction with it. However, on the downside, there is a lack of direct manipulation or control of confounding factors in the experiments. For the classical psychophysics (PP) type of test environments (that is, methods of studying the relationship between body and mind, usually carried out in laboratory situations), experiments can be well controlled but with very low levels of realism and with only limited interaction with the environment. Computer graphics psychophysics (CG) can provide a high level of realism along with control of the experiments, but there is not much interaction with the environment. VR, in comparison with these other test environments, can produce high levels of realism and environmental interactivity, whilst retaining a sufficient level of control over experimental conditions. Although there are concerns regarding the similarity of the experiences, memory and knowledge acquired between the real world and virtual reality (discussed in Chapter 4), the emphasis of this VR-based test environment is upon the way in which individuals complete their wayfinding tasks and interact with mobile devices for accessing information.

The desired objective in the research reported here was for participants to replicate their usual wayfinding strategies in the VR test environment. In order to test the extent to which this was achieved, a debriefing questionnaire and interview was set up for obtaining participant feedback with regard to this issue (discussed further below).

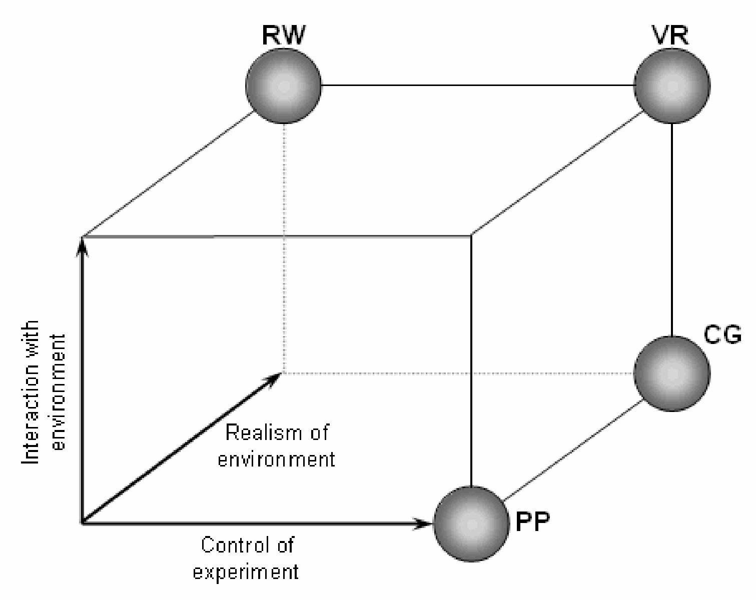

Figure 5.3 A range of experimental methods in relation to characteristics of interactivity, realism and control. (RW = real world experiments, VR = virtual reality, CG = computer graphics psychophysics, PP = classical psychophysics). Adapted from Mallot *et al.* (2002).

Within the test environment, and on the basis of knowledge of the literature, it was considered important to create contrasting urban settings. The reason for this derives from the fact that individual wayfinding strategies may be influenced by the urban morphology itself (Lynch, 1960; Gollege and Stimson, 1997). Consequently, and as further described in detail in Chapter 6, two contrasting urban models were constructed with their own distinctive layouts and mix of architectures. The layout of one of them is characterised by grid-like street patterns and modern low-rise housing. The other is characterised by a more irregular layout with the features of a traditional market town. Both are modelled on real UK towns.

The second component of the test environment is an information source delivered via a mobile device. This is an important new element in VR-based wayfinding experiments that allows participants to undertake more complex tasks since they have an interactive source of information upon which to call for assistance. A key theme of the mobile device is to simulate LBS wayfinding applications so as to research likely information usage from such services. The information that could be delivered via a mobile device could take a number of forms, including written text, the spoken word, graphical symbols, photographs, 2D maps, 3D maps, video clips, VR scenes, and audible tones. For the purposes of the experiments, the mobile device was a PDA with modes of communication restricted to text, voice and 2D maps (general layout map and zoomed-in detailed maps). This moves beyond the use of a single mode of communication for delivering information (most frequently the map) and allows wider testing of preferences.

The third component of the test environment is the multi-source data collection method. The objective of setting up this test environment is to study the interaction between the individual, the mobile device and the environment. One of the challenges has been to capture this process. Therefore, a multi-source data collection method has been established in the test environment which is able to capture and integrate spatio-temporal data of respondent position/location within the environment, data on information access via the mobile device and data on respondent behaviour. This aims to ensure that adequate data are collected with which to analyse the interactions and information transactions. The data thus collected would include: positional data; information usage (frequency, types of spatial information accessed and used) through the PDA; participant actions and reactions through observational data.

The experiments to be carried out in the VR-based test environment discussed above were in the form of having to complete sets of wayfinding tasks. In general, three broad categories of wayfinding tasks have been recognised (Allen, 1999). The commuting type of wayfinding concerns travelling between familiar places along familiar routes. The exploratory type mainly considers the activities of exploring a surrounding environment starting from a familiar place and returning to the place of origin. Goal based wayfinding relates to tasks when travelling to reach some novel destination(s). This last type of activity is often assisted by the provision of spatial information either via maps or instructions. The wayfinding experiments in this research were set up based on this last type of wayfinding activity, which will be referred to as 'task-based wayfinding' in this thesis.

The objective of the research is to study spatial information transactions and the nature of interactions between individuals, mobile devices and environments. In the set up of the task-based experiments, individuals were required to complete sets of wayfinding tasks in order to find pre-specified destinations in two different urban settings. During the wayfinding tasks, individuals could utilise a mobile device in order to retrieve spatial information that would assist them in completing their tasks. The mode of travel in the experiments was set as pedestrian. Compared with other modes of travelling, pedestrian wayfinding has fewer constraints on the way in which participants could access information. For example, one should not study maps in detail or read written instructions while driving, nor can one stop or necessarily reduce speed at any location whenever one desires in order to request and absorb information. There are also spatial constraints such as one-way systems and general conventions of the Highway Code.

For the settings where the experiments were to take place, urban areas were considered most appropriate. Urban areas provide a level of complexity that is yet tractable for wayfinding activities, whereas rural areas might have less changeable features and more open space in similarly sized spaces. Moreover, wayfinding in urban and rural areas are quite different in terms of orientation, view points, landmarks and distance. Consequently the types and levels of information required would also be different. The scope of this research is focused only on pedestrian wayfinding in urban areas. Moreover, the urban areas for carrying out the experiments were set up as un-familiar areas for all participants, aiming to eliminate the different levels of previous knowledge that might occur amongst the participants. Each participant would therefore commence the tasks on an equal footing. Before starting wayfinding experiments, a training session was introduced for all participants in a similar way to which experiments would be carried out, but in a different, much simpler urban setting. The purpose was to familiarise participants with the equipment, environment and procedure, and to reduce the learning curve effect during the main experiments. Two sets of wayfinding tasks were set up, with one set of tasks to be carried out in one urban setting and with another similar set of tasks to be carried out in another (see §6.4 for detail). The sequence of these two urban settings was alternated amongst the participants in order to counterbalance, and allow study of, any further learning effects that might occur. Another aspect of setting up the wayfinding tasks was the provision of information for assisting participants in completing the tasks. The spatial information transaction was aimed to be recorded through the actual wayfinding activities during the experiments. Therefore, an approach of 'choose information as you prefer' was adopted. That is, all participants could access the available information from the PDA as they needed at any time. This was aimed at reducing any bias that would undoubtedly arise where groups are pre-assigned a specific mode of information, regardless of any differences in individual information preferences amongst the participants.

The objective of setting up post-experiment questionnaires was to elicit feedback from participants after each set of wayfinding tasks, in order to reflect upon the following three aspects:

- Participant feedback on their experience of a VR environment regarding their 'sense of presence' (discussed in Chapter 4). More importantly, participant feedback on the commonality between their wayfinding strategies used in a virtual test environment and those used by them in the real world.

- The usefulness of the information provided through the PDA.
- Conventional route description and sketch map drawing to recall their journey.

The questionnaire was devised in two parts. Post-experiment question part 1 was to be carried out after the completion of the first set of wayfinding tasks, while part 2 was implemented after the completion of the second set of wayfinding tasks. The emphasis of questionnaire part 1 was upon participant experience in the VR test environment, such as their sense of 'being there', and the commonalties between wayfinding approaches adopted in the VR environment and those used in the real world. Drawing of a sketch map of the area with routes and any remembered features was also required. Route description and sketch map drawing tasks were ways to measure individual spatial knowledge gained (as discussed above) as a static situation.

In order to establish whether there was consistency in the feedback in the similarity of wayfinding strategies used in VR and in the real world, these same two questions were repeated in post-experiment part 2. The emphasis of the questions in part 2 was on the use of the information provided through the PDA, acting as the mobile device. The same route description and sketch map drawing tasks were also included here.

The purpose of setting up an informal de-briefing interview, after the experiments, was to confirm that all questions had been answered and fully understood as well as to provide an opportunity for participants to raise any particular issues they wished to address. Moreover, general participant feedback was solicited on their wayfinding experiences in the VR test environment in this informal de-briefing interview, particularly with regard to any differences in the wayfinding strategies that respondents used in their daily life when compared to those adopted in the VR test environment. All interviews were loosely structured around these purposes.

The objective of setting up a multi-source data collection method was discussed earlier in this Section and is a key component of the methodology. This method was devised to enable collection of data in real time, at a detailed level of spatial granularity, and for multiple variables including location, time, information access, information usage and overt actions. Data were collected for each individual while he/she was performing the wayfinding tasks. Data on location and information usage were collected through automated methods through a series of existing and specifically programmed software. Observation methods were also applied during the experiments.

All of the elements of the methodology described here were developed and honed through a cycle of design, prototyping, testing, design improvement and utilisation for the final experiments. The testing of the prototyped elements is described in Chapter 6.

The data collected from the questionnaires and the experiments were intended to be integrated and analysed at different levels (individual and aggregate) and from different aspects. Both quantitative and qualitative analyses were deemed necessary in order to leverage maximum insight from the research.