CHAPTER SIX
Design and Setup of the Experiments

Following the methodology established in Chapter 5, this Chapter focuses on the design and set up of the experiment and all its elements. The Chapter is structured into five sections. The first Section describes how the pre-experiment questionnaire was complied. In §6.2, the creation of a test environment, which consists of implemented VR urban models, simulated wayfinding assistance delivered via a PDA and a multi-source data collection method, is described. §6.3 describes the set up of the two parts of the post-experiment questionnaire. §6.4 provides a description of the design of the task-based wayfinding experiment procedure. Finally, §6.5 describes the implementation of a prototype prior to conduct of the main experiment.

6.1 Creating a pre-experiment questionnaire

As discussed in the previous Chapter, the main objective of this pre-experiment questionnaire is to obtain background information about participants, including their demographics, self-assessed spatial abilities and their familiarity with a range of technologies. The intention is to analyse these data alongside the behavioural data recorded during the experiments. Although some of the data collected may not be used as variables in later analyses, such as age, ethnicity and occupation, the data provide some level of understanding of the individual participants and the generalisability of the research findings. Another reason for the timing of this questionnaire before the experiment is so that individuals' assessments of their spatial abilities will not be influenced by their experience of the wayfinding experiments.

The pre-experiment questionnaire was designed to be self-administered, which means that participants would be required to record responses to all questions without investigator supervision. All questions were structured with tick boxes indicating the degree of accord with the given statements, and all questions were closed. The content of this pre-experiment questionnaire was structured into four main parts:

- demographic information;
- self assessment of spatial ability;
- familiarity with related technologies;
- spatial-visual test.

Following the first part of the questionnaire requesting an individual's gender, age, ethnicity, qualification and occupation, the main part of the questionnaire aimed to measure individual spatial ability through a range of attitude-focused questions. In this part, the questions were devised with reference to other pre-existing questionnaires discussed in the literature (e.g. Montello *et al.*, 1999, Pazzaglia and De Beni, 2001; Hegarty *et al.*, 2002). The aspects of individual spatial ability are discussed in §3.2.2. The questionnaire was initially structured to reflect different aspects of people's spatial abilities and awareness using 21 questions. Table 6.1 lists the 21 questions (Q1 to Q21), grouped into nine aspects marked as A1 to A9. These nine aspects include sense of direction, preference for image thinking or verbal thinking, tendency towards landmark/route/map (configurational) thinking, as well as map usage, general ability in performing spatial tasks and spatial awareness. Aspects A4 through A6 are not intended to be mutually exclusive but aim to establish any tendency in the preference for the three generally recognised types of spatial knowledge (landmark, route, configurational) as discussed in Chapter 3. The draft questionnaire was then tested on 89 participants. The process of evaluating the questionnaire will be discussed in detail in §6.5.1. After analysing the results of the questionnaire and considering the feedback from the participants, a number of modifications were made. Reasons for these modifications can also be found in §6.5. The revised version of the questionnaire, shown in Table 6.2, has seven aspects with the seventeen questions. Tick box answers to the questions were designed on a six point scale based on the level of agreement with the question posed from 'strongly agree' to 'strongly disagree'.

A1	sense of direction	**Q1** My "sense of direction" is very good. **Q2** My family/friends think that I have a good sense of direction. **Q3** When I'm in a complex building (many floors, stairs, corridors), I can indicate where the entrance is immediately. **Q4** When I'm in a natural, open environment (e.g. countryside), I naturally know where north, south, east, and west are. **Q5** When I'm in my hometown, I naturally know where north, south, east, and west are.
A2	preference of image thinking	**Q6** When someone is describing to me the route to reach an unfamiliar place, I prefer to make an image of the route.
A3	preference of verbal thinking	**Q7** When someone is describing to me the route to reach an unfamiliar place, I prefer to remember the verbal description.
A4	tendency towards route thinking	**Q8** I usually orientate myself by remembering routes connecting one place to another
A5	tendency towards landmark thinking	**Q9** I usually orientate myself by looking for features (landmarks) that are well-known to me.
A6	tendency towards map (configuration) thinking	**Q10** I usually orientate myself by trying to create map-like image of the area.
A7	Map use	**Q11** I like using maps. **Q12** I am very good at reading maps. **Q13** After reading a map once, I need to keep referring to it in order to find my way.

A8	general spatial ability, such as judging distance, wayfinding	**Q14** I am very good at judging distances. **Q15** I do not get lost very easily when visiting unfamiliar places. **Q16** I don't confuse right and left turns. **Q17** I remember routes very well while riding as a passenger. **Q18** If I go to a new place, I easily know the way back.
A9	spatial awareness and spatial anxiety	**Q19** I'm confident in finding my way when going to new places. **Q20** It is important to me to know where I am. **Q21** I like to explore unfamiliar places.

Table 6.1 The initial version: nine aspects relating to individual's spatial ability (questions subsequently dropped/modified are printed in grey).

A1	sense of direction	**Q1** My "sense of direction" is very good. **Q2** My family/friends think that I have a good sense of direction. **Q3** When I'm in a complex building (many floors, stairs, corridors), I can indicate where the entrance is immediately. **Q4** I tend to think of my environment in terms of cardinal directions (North, South, East, West). **Q5** I am very good at giving directions.
A2	tendency towards route thinking	**Q6** I find my way best by remembering the routes connecting one place to another.
A3	tendency towards landmark thinking	**Q7** I find my way best by looking for recognisable features (landmarks, e.g. pub, petrol station).
A4	tendency towards map (survey) thinking	**Q8** I usually orientate myself by trying to create a map-like image of the area.
A5	Map use	**Q9** I like using maps. **Q10** I am very good at reading maps.
A6	general spatial ability, such as judging distance, wayfinding	**Q11** I am very good at judging distances. **Q12** I do not get lost very easily when visiting unfamiliar places. **Q13** I remember routes very well while riding as a passenger. **Q14** If I go to a new place, I easily know the way back.
A7	spatial awareness and spatial anxiety	**Q15** I'm confident in finding my way when going to new places. **Q16** It is important to me to know where I am. **Q17** I like to explore unfamiliar places.

Table 6.2 The revised questionnaire: seven aspects of people's spatial ability.

The third part of the questionnaire consists of a number of fact-focused questions on the individual's usage of related technologies. Through these questions it should be possible to detect variations amongst the selected participants in terms of familiarity with technologies. If familiarity were at different levels then its influence on the wayfinding experiments may need to be considered. The first four questions were designed to elicit frequency of usage of mobile phones, palm computers, text messaging and electronic games. The frequency rate was set from daily use, 2-3 times a week, occasionally use, rarely use and never use. The next question was about using maps and/or travel instructions through the Internet. Considering the general usage differences of mobile devices and map/travel information sites, the question was set up using a different scale as weekly, monthly, 2-5 times year, rarely and never. An additional question was about the experience of various types of virtual reality. The responses from these questions would give a good indication on the level of familiarity with these technologies among the selected participants. The full pre-experiment questionnaire can be viewed in Appendix II.

The last part of the pre-experiment questionnaire (see Appendix II) entailed a visuo-spatial test. The test was created for this research based on a visuo-spatial ability test used by the Department of Radiography at City University for testing aptitude in students. The test consists of five questions (Appendix II) with an intention of gradually increasing complexity. All five questions involve mental manipulation and visualisation of images and objects (see §3.4on psychometric measurement in Chapter 3). It is recognised, however, that this type of test may be a weak indicator of wayfinding ability (Sholl, 1998; Tackeuchi, 1992), but was included nevertheless in order to gain better understanding of individual ability.

6.2 Building a test environment

A test environment was set up for carrying out experiments to study the interactions and information transactions between environments, individuals and mobile devices. This Section describes in detail how such a test environment was created. The test environment was designed around three main components:

- Virtual Reality (VR) urban models and a projection system, which allowed individuals to 'walk around' at street level with realistic views;
- a mobile device (a PDA), used to provide a simulated LBS , providing route and map wayfinding assistance to people on the move;
- software for multi-source data collection, to record participant actions, interactions and reactions during experiments within the test environment.

6.2.1 Test environment part 1 – VR urban models

There is an important distinction between VR models, which offer the ability to walk through realistic street scenes, and other models which are created for birds-eye views and 'fly throughs' of urban areas but which do not contain the necessary realism at street level. These two approaches serve different objectives (Batty & Smith, 2002). The objective of the VR models in this test environment is to create sufficient realism at street level such that participants, as pedestrians, might reasonably be expected to behave (in wayfinding terms) as they would in a real street scene (discussion on this is provided in §6.2.3 with respect to a post-experiment questionnaire and in Chapter 8 with respect to analysis of the experiment results). This has implications for the level of detail that needs to be achieved and the corresponding consistency of that detail (Tromp et al., 1998). The focus here is on the construction of urban VR models since the studied wayfinding activities are in urban areas. A four stage process has been adopted in creating the urban VR models, as illustrated in Figure 6.1.

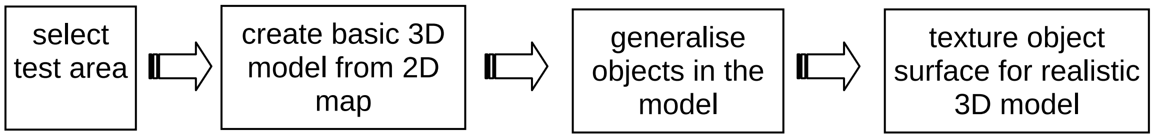


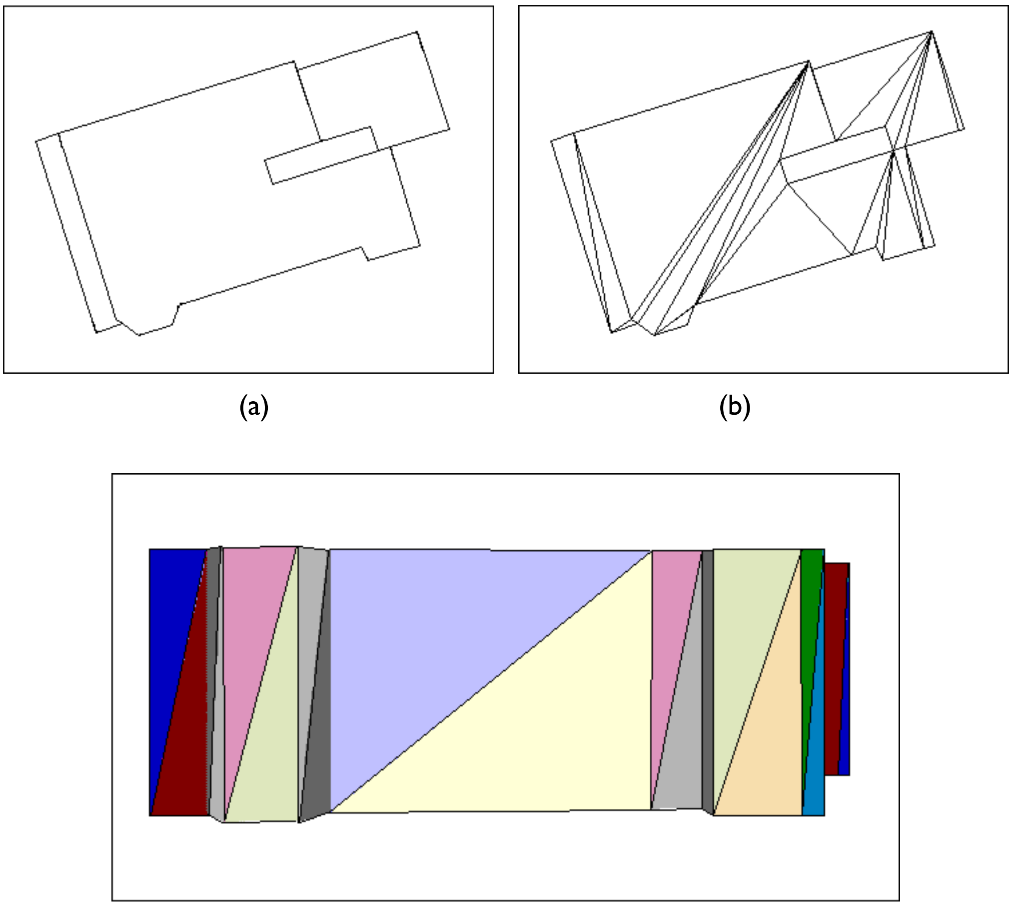
Figure 6.1 Four stage process of VR model creation.

Test areas need to be carefully selected so that they are suitable for achieving the specific experimental objectives, that is, they contain the types of features pertinent to testing a particular set of wayfinding activities. Moreover, the layout of the specific built environment is likely to affect how participants will respond to them in different situations (Lynch, 1960; Gollege & Stimson, 1997). In order to reflect this, more than one model has been used. Thus, two contrasting urban models have been constructed, each having its own distinctive layout and mix of architectures. The layout of one of them is characterised by grid-like street patterns and modern low-rise housing, covering an area of approximately 48 hectares (approx. 800m by 600m). The other is characterised by a more irregular layout with the features of a traditional market town, covering an area of approximately 35 hectares (approx. 700m by 500m). The layouts of these two selected areas are shown in Figure 6.2 (a) and (b) respectively. These two urban models will be referred to as urban setting U1 and urban setting U2 throughout the thesis. Both are modelled on parts of real UK towns: a residential area of Milton Keynes and the town centre of Saffron Walden. Although both are mentioned in the Doomsday Book (1086), Milton Keynes was planned and developed as a new town starting in the 1960s, whilst Saffron Walden has retained its basic old street layout and many old building styles. Almost all of the features in these two models were based on the reality of both areas. The only exceptions to this rule for setting U1 were the changes of the destination landmarks to make them more easily recognised for the purpose of wayfinding experiments. These were: a modern church façade and its spire used to replace a Christian Centre that, in reality, had a very similar façade to the surrounding buildings; a typical corner shop type of post office and a McDonalds fast food restaurant were added at two destination locations; and a cinema façade was added instead of the original building façade at another destination. For the same reason, in setting U2, the features which are different from the reality are the names of shops and pubs (not the buildings themselves) such as the name of the superstore and the name of the 'George and Dragon' pub.

Figure 6.2 Plan view of the two selected urban areas: (a) setting U1; (b) setting U2.

Having selected test areas, the next stage was to create basic three-dimensional (3D) models from two-dimensional (2D) digital maps. Initial 3D models were generated by extruding objects presented in 2D maps. Great Britain's national mapping agency, Ordnance Survey, agreed to provide digital map data for these two selected areas. The map product provided was MasterMap™ (www.ordnancesurvey.co.uk/oswebsite/products/osmastermap). Ordnance Survey's MasterMap™ offers image, polygon, line and point data at sufficient resolution for building urban models. The imagery layer is fully orthorectified aerial photography in 24 bit colour at a 25cm resolution. Its use in urban VR modelling is limited to providing a textured ground surface, where desired. Draping of the orthorectified imagery layer onto extruded objects cannot provide adequate realism in these VR models since for buildings only roofs (not usually visible in street scenes) are well represented but not their façades. The topographic layer contains polygon, line and point features which for urban areas are at a notional scale of 1:1,250. These features (over 400 million in the UK) are organised into 21 descriptive groups of real-world topographic objects (Ordnance Survey, 2001). Of greatest interest for building VR models are the polygon features (buildings, roads) and some point features which can be used to position trees and street furniture. Polygon features are easily extruded using GIS software, though additional attributes on building heights need to be obtained from other sources (e.g. LiDAR). Also, whilst MasterMap™ provides detailed geometry of the footprint of buildings, it does not provide roof geometry and this either needs to be interpreted from the imagery layer or constructed using LiDAR data. For street-level VR applications, where roofs are rarely in full view, this is not the significant problem that it would be for 'fly through' visualisations. The reason for using existing mapping as the basis for constructing the VR models rather than devising new models was to ensure that the urban morphology was as close as possible to reality so as to help ensure the validity of the wayfinding experience.

For the two urban models in this research, the real-world objects in the 2D topographic layer were generalised at the attribute level prior to extruding them into 3D models. Thus by inspection of the MasterMap™ 'Legend' attribute and the 'Description Group' attribute, objects were re-classified into five main categories: special landmarks which would need to be specifically constructed in 3D (e.g. churches), buildings, roads, natural surfaces (e.g. green space) and walls/hedges. The initially clipped areas that would form the two VR models comprised 3954 and 2235 individual objects respectively. Height data were assigned to each object according to the generalised category to which they belonged. Building height attributes were calculated according to broad architectural types and the number of floors was obtained from field observation. For example, old traditional houses and historic landmarks were treated differently to modern office-like buildings, even though all may be described as 'low rise'. Natural surfaces and roads were given notional heights of 0.1m. 3D models were then extruded from the 2D map data using ArcGIS™ and exported as Virtual Reality Modelling Language (VRML) format. However, the objects in the urban models extruded in this way have many surfaces because of the complex shape of buildings and the way by which ArcGIS™ extrudes objects as triangular facets. Taking a building object as example, Figure 6.3(a) shows the footprint of a single building object in 2D map format (from OS MasterMap™), whilst Figure 6.3(b) shows the plan view of the extruded 3D object of the same building. Figure 6.3(c) is a façade (profile) view showing how the triangular facets make up the façade (coloured to assist visualisation). Although the basic extrusion technique provides generally realistic structures upon the digital foundations of building footprints, difficulties nevertheless arise in texturing buildings using digital photographs of the facades. Furthermore, complex feature geometry creates very large executable files which become difficult to run as smoothly flowing VR models. For this reason, our models required further generalisation, pruning and simplification.

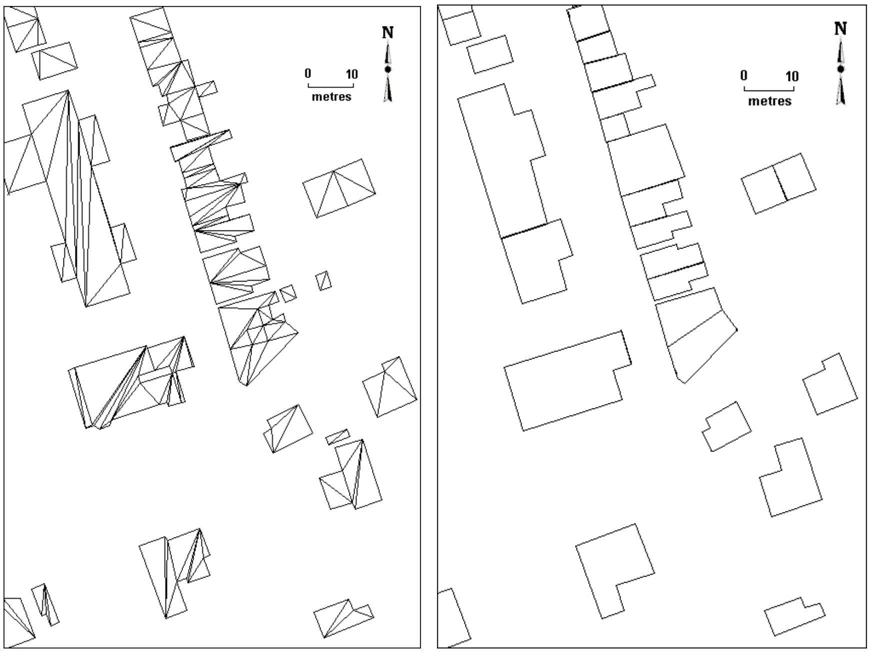


(a) (b)

(c)

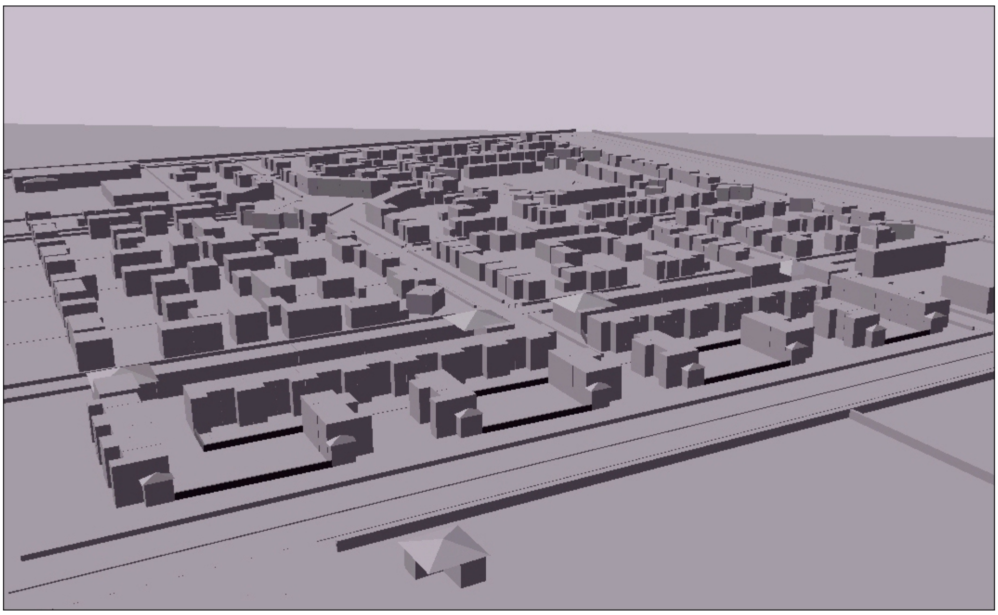
Figure 6.3 A single building object: (a) the footprint of the object from OS MasterMap; (b) the plan view of the extruded object; (c) façade view of the object.

The next stage of creating the VR models was to generalise objects in the models. In setting up test environments, it is both unnecessary and difficult to provide exact replicas of real urban areas. The models were created with the aim of having consistent degrees of abstraction and detail whilst retaining sufficient realism for the application at hand. In this research, the smooth running of a VR model with natural perspective views was assigned higher priority than incorporating precise details of the geometric shape of buildings and roads. Thus a generalisation process was applied to the geometric shapes of objects in the two models. The generalisation process adopted here has been based on similar principles to those of map generalisation (McMaster & Shea, 1992; Muller et al., 1995). First of all, simplification was applied particularly to shapes of buildings and road objects, with aggregation also on buildings and hedge objects. These processes were carried out manually, mainly through a consideration of a desired set of criteria on shape, location and the character of entire objects. This was thus based on the principles of generalisation rather than on specific vector and/or raster generalisation algorithms. Taking the example of road features, road lines were considerably simplified through reducing the number of points along the feature lines on the basis of still retaining the general character of roads such as straight, bend, main and side road, various types of junctions and roundabouts. For building features, minor details were reduced through simplifying building outlines, but the general shapes with their location were maintained. Triangulated objects within single buildings were aggregated into a single building object. Small clusters of hedges were aggregated into lines of hedge, while public greens and domestic gardens were aggregated into one category named as 'natural surface'. Furthermore, amalgamation was carried out on numbers of fragmented in-road and roadside features. For instance, 'sleeping policeman' features were combined into the category of roads together with the pavement features. In addition, there was also selective removal of objects where they contributed little to the overall objective of the test environment, such as outbuildings not visible from the street by a pedestrian. Figure 6.4(a) and (b) show the plan view of a group of building objects in the setting U2 before and after the generalisation process. However, some specific features such as churches, museums and monuments have been left with much more detail and with a lesser degree of generalisation of their geometric shapes in order to more fully capture their unique character. In the final generalised models, there are 1250 buildings in the setting U1 and 780 buildings in the setting U2. The two urban VR models (without textures at this stage) are illustrated in Figure 6.5.

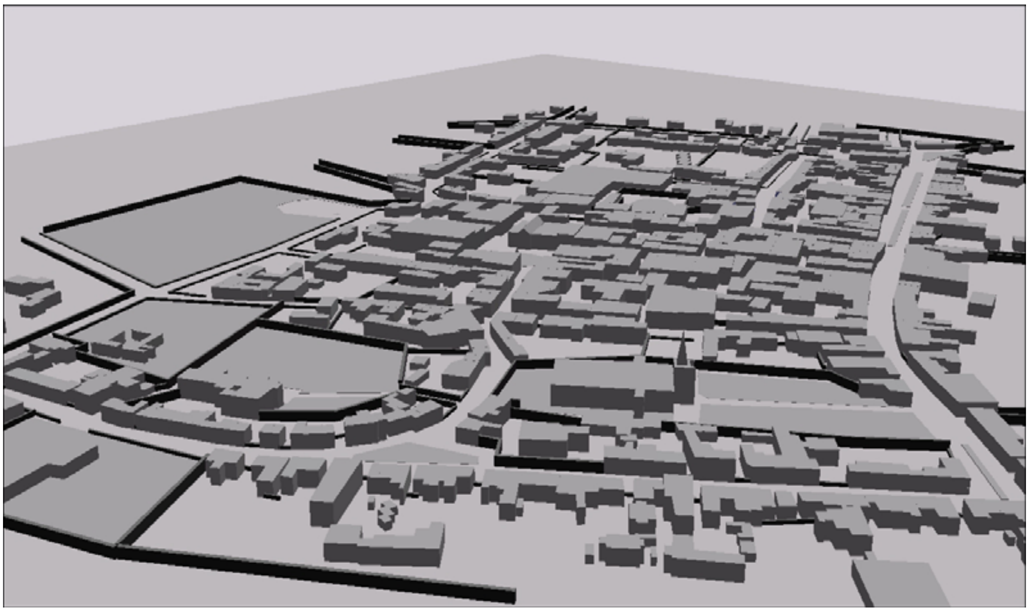


(a) (b)

Figure 6.4 The plan view of a group of building objects in setting U2: (a) before the generalisation process; (b) after the generalisation process.



(a)



(b)

Figure 6.5 Two basic urban VR models: (a) urban setting U1 viewed from the east; (b) urban setting U2 viewed from the north (for maps see Figures 6.2(a) and (b) respectively).

The last stage of creating the VR models was to texture object surfaces for photo- realistic 3D models. The main factors that were considered for texturing the facets of 3D objects in the test environment were: realistic appearance, vistas and consistency in the level of detail. Here, the purpose of texturing 3D objects was to create street-level realism in the VR test environments, from the perspective of someone walking along a street. The approach was to use street-level digital photographs taken during field work to capture a range of textures that exist. However, issues of overall file size restrict the number of photographic images that can sensibly be used and their resolution (dots per inch). For large, bulky models, an important parameter for the projection of VR scenes is the distance threshold for object inclusion in a scene. Thus, if set for example at a 100m threshold, models will run faster and smoother than if set at 500m, but any vistas will be limited to 100m. On the other hand, using the whole area without restricted vistas would give participants a much more realistic feeling of the walk through. Therefore, there is a trade-off between this parameter and the length of vistas that must be accommodated in order to maintain realism. This trade-off can be offset by reducing the numbers of individual photographic textures used and by lowering image resolution. For the models in this research, in order to maintain larger vistas, the resolution of photographic images was systematically degraded to a degree that was considered not to compromise building realism. In this way, sufficient variety of textures could be achieved in a smooth running VR model. All digital photographs were taken from real sites at Milton Keynes and Saffron Walden during field work. They were then rectified in

Adobe Photoshop and reduced to the same level of resolution and then pasted onto building façades. In total, 111 photo-realistic images were created for setting U1 (based on Milton Keynes) and 162 for setting U2 (based on Saffron Walden). The buildings in different districts were textured on the basis of the characteristics of those districts (see Appendix III). Inevitably, each photographic image has been used a number of times. Thus, the term 'repeat rate' has been used, for this purpose, to refer to the number of times that a photographic image has been used. It was defined as:

- repeat rate as zero: for images used only once
- low repeat rate: for images used >1 and <=5
- medium repeat rate: for images used >5 and <=10
- high repeat rate: for images used >10 times

In the urban model presenting setting U1, where there are large numbers of similar style houses in this residential area, each photographic image was used on average sixteen times. For special landmark buildings, images were used with repeat rate as zero, such as the church, the monument, the cinema and McDonald's. Some areas were identified as suitable for using images at medium repeat rate, whilst others were deemed suitable for high repeat rate. For the model representing setting U2 which is the central area of a traditional market town, each photographic image was used on average seven times. Similar to the setting U1, special landmarks were textured at zero repeat rate. The areas with shops were identified for using images at low repeat rate. Medium repeat rate was used for the areas with similar style of houses along the streets. In both models, these repeat rates were decided in the light of field inspection and were consistent with the variety of buildings encountered in the real environments. Roads, walls and hedges were also textured using photo-realistic images. Sample scenes from both VR models are given in Figure 6.6 and Appendix III.

(a)

(b)

Figure 6.6 Sample scenes from both urban VR models: (a) a view from model U1; (b) a view from model U2.

Another important and unique feature in urban environments, which cannot be extruded from 2D maps automatically, is street names and other signage. In our VR urban models, street name signs were added as additional object features. Two different forms of these 3D objects were created for the different urban settings according to their appearances in real environments. One was treated as a plaque object seen fixed on walls, and the other was as a street sign object mounted at the side of streets (see Figure 6.7).

Figure 6.7 Examples of street signs used in the VR models.

An additional small VR model was created for the purpose of carrying out a training session for participants to familiarise themselves with the technologies and being in an immersive VR. It was built in a similar way as described above. However, the model was not based on any real areas, with a simple spatial layout containing five streets. The main characteristic of the area was a mix of residential houses and a store and a couple of restaurants. It also contains two types of street signs used for urban settings U1 and U2.

A number of elements have not been built into the VR models, such as topography of the areas, street furniture, moving traffic and people. For the topography of setting U1, the real world area of setting U1 is quite flat terrain, therefore the area in VR model setting U1 with flat terrain quite reflects the area. For the real world area of setting U2 there is slight valley running through the centre of the town with a slight incline to the north where the church is located. This was not reflected in the VR model. The view of the church was not affected as the church spiral could still been seen from a distance. Moving cars and people have not included in the current VR models. Different elements in the VR models should be presented with a consistent level of detail (Vinayagamoorthy, 2004). Creating moving traffic and people and building them into the models at a similar level detail to the rest of the urban model created a challenge that would have needed more extensive research, and therefore can be considered in future research. A range of street furniture will also be considered in future studies.

6.2.2 Testing environment part 2 – information source

The mobile device is an important component of the test environment, since it acts as an information source that can be accessed interactively as a simulated LBS application. The information 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, audible tones and so on. At present, the mobile device is taken to be either a PDA or a mobile phone, and in this research a PDA was used with modes of communication available as text, voice and 2D maps.

The structuring of information on a PDA needs to address the issues of mode of communication and level of detail provided. The approach adopted here was to use parallel strands for each mode of communication (e.g. text, voice, maps), structured hierarchically with increasing levels of detail, and to permit switching between modes. Thus in this test environment, provision was made for simulating LBS wayfinding instructions as text, voice and maps which were selectable according to each individual's personal preference. Information for any defined geographical area was then organised into three levels of detail. In each mode of communication, individuals could access information initially in a general form and then drill down to more specific information content. Thus in order to offer pedestrian wayfinding assistance, text instructions started with a list of routes identified by their start location and destination and followed by general route information on each route with further detailed instructions available for each section of route. Instructions in voice mode were designed in the same structure as the text instructions. For information presented as maps, the top level was a generalised sketch map featuring street layout. At the next more detailed level, various landmarks and road names could be overlaid onto the sketch map. A final option was to zoom the map to show the most detailed level of information. Figure 6.8 shows the general structure of the information on the PDA.

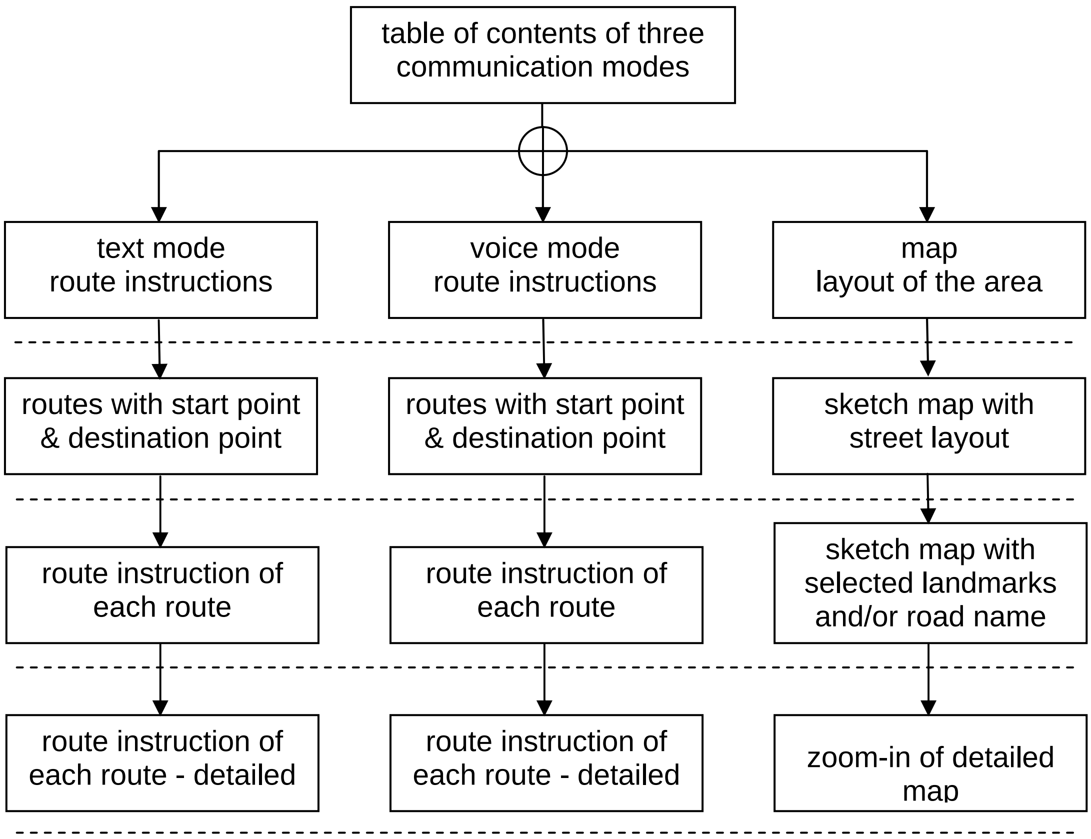


Figure 6.8 The structure of the information content on the PDA.

Having designed the structure of information on the PDA, the detailed content of the information was organised into two groups: route instructions from starting point to destination point for text and voice mode; and maps of the defined areas. Route instructions provide the sequential type of information using various features along and/or visual from the selected route and physical activities (e.g. turn, walk along) (Denis, 1999; Lovelace *et al.,* 1999). There is no consensus in the literature (Lovelace *et al.,* 1999) as to which components should be included in 'good route directions'. Suggestions have been made on the elements of route instructions. Such elements include upcoming points of choice, instructions for proceeding at choice points, use of landmarks (at choice points or along routes), use of directions, use of distances, use of linear sequential information and use of other instructive information (Wunderlich and Reinelt, 1982; Allen, 1997; Denis *et al.*, 1999). For the route instructions that were designed for the test environment, there were three main elements: direction/action from the starting point, actions/directions along the route and action toward destination point. Also the actions (e.g. turn left) were composed of the consistent components which were landmarks, orientations and actions, for example, 'at a location (e.g. the Cross-Keys Pub, or the T-junction at the end of some street) turn left'. The landmarks mentioned were either along the route or visible from the route, which could either be buildings (such as shops, pubs) or be road signs and road structures (square, roundabout, junctions). Another group of content information was presented as maps. The maps were used to show the layout of the surrounding area of wayfinding paths and destinations. As in most popularly used web sites for finding destinations (e.g. www.streetmaps.co.uk, www.multimap.co.uk, www.maps.google.com and www.mapquest.com), maps can be viewed at different scales with different levels of detail. In this test environment, maps were organised into two levels: one level of sketch map showing road layout with display of interactively selected landmarks and road names, and another level of zoom-in map with more detailed information in one part of the area at a time. In addition, there was also the information pertaining to the exact current position of individuals, which could theoretically be displayed on the PDA. However in this research, this information was not included. The reasons for this are twofold. Firstly, although the locations of individuals can be identified in the real world through location-aware PDA, this would be to different levels of accuracy depending on the positioning technologies used (GPS, cellular network based) and the nature of urban area (high-rise city centre, low-rise suburban). Hence, given current technologies, the location of PDA cannot accurately and consistently be expressed as a point in urban areas. Secondly and importantly, by not providing exact current position all participants are put on an equal footing regardless whether maps, voice or text are being used.

Following the defined structure and content of information, it was necessary to design a user interface for accessing information on the PDA. There were two broad options: it could either be a proprietary interface on the Windows CE platform, or developed using markup languages (e.g. HTML) and Java for an interface using an Internet browser. Both methods were explored in this research. Use of Visual Basic on a Windows CE platform offers flexibility of programming and style of presentation. On the other hand, use of a Web browser style interface provides for easy adoption on any device. Its style is also more intuitive, corresponding with people's experience of the Internet and thereby reducing the gradient of the learning curve in using any application. In addition, it provides an easy environment for modifying and testing the information content of pages. For this reason the

Web browser approach was adopted here for the display and access of information on the PDA. According to the structuring of content as discussed in the previous paragraph, Figure 6.9 illustrates a part of the Web page structure employed for the setting U2 and the hypertext links between them. On the PDA, navigation between pages is by means of touch screen using the handheld stylus.

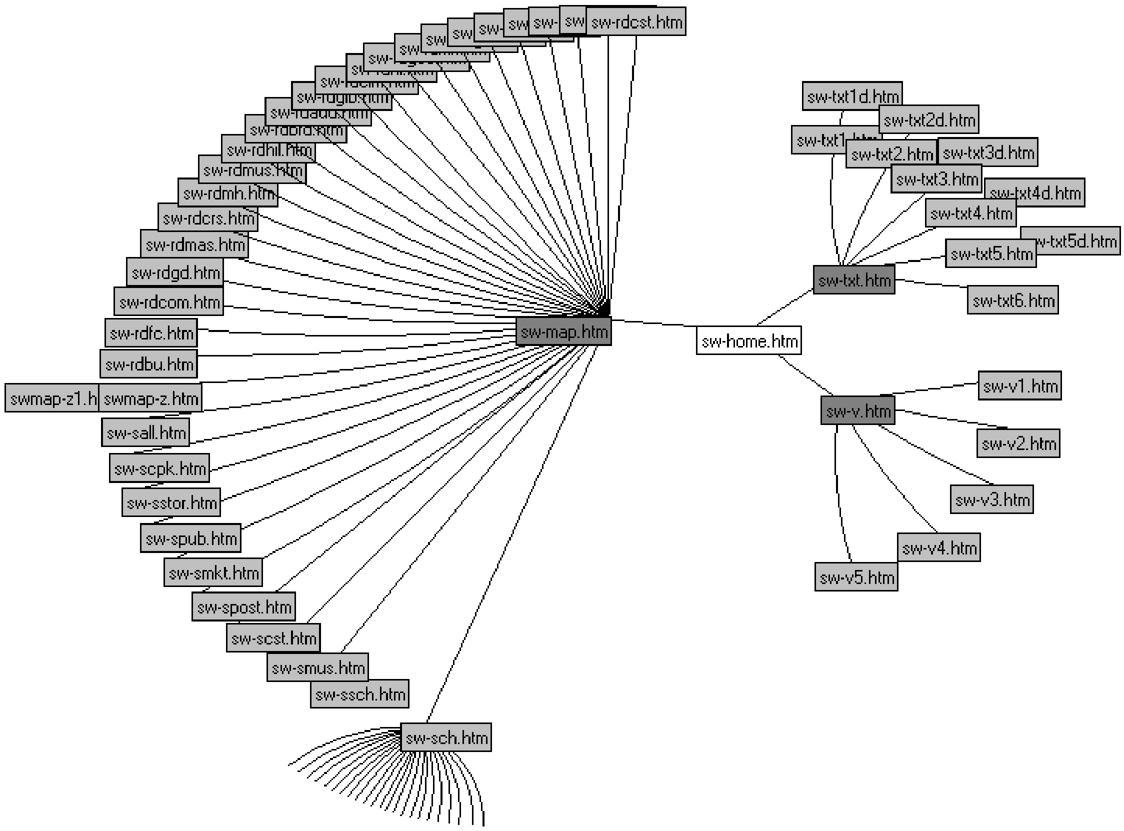
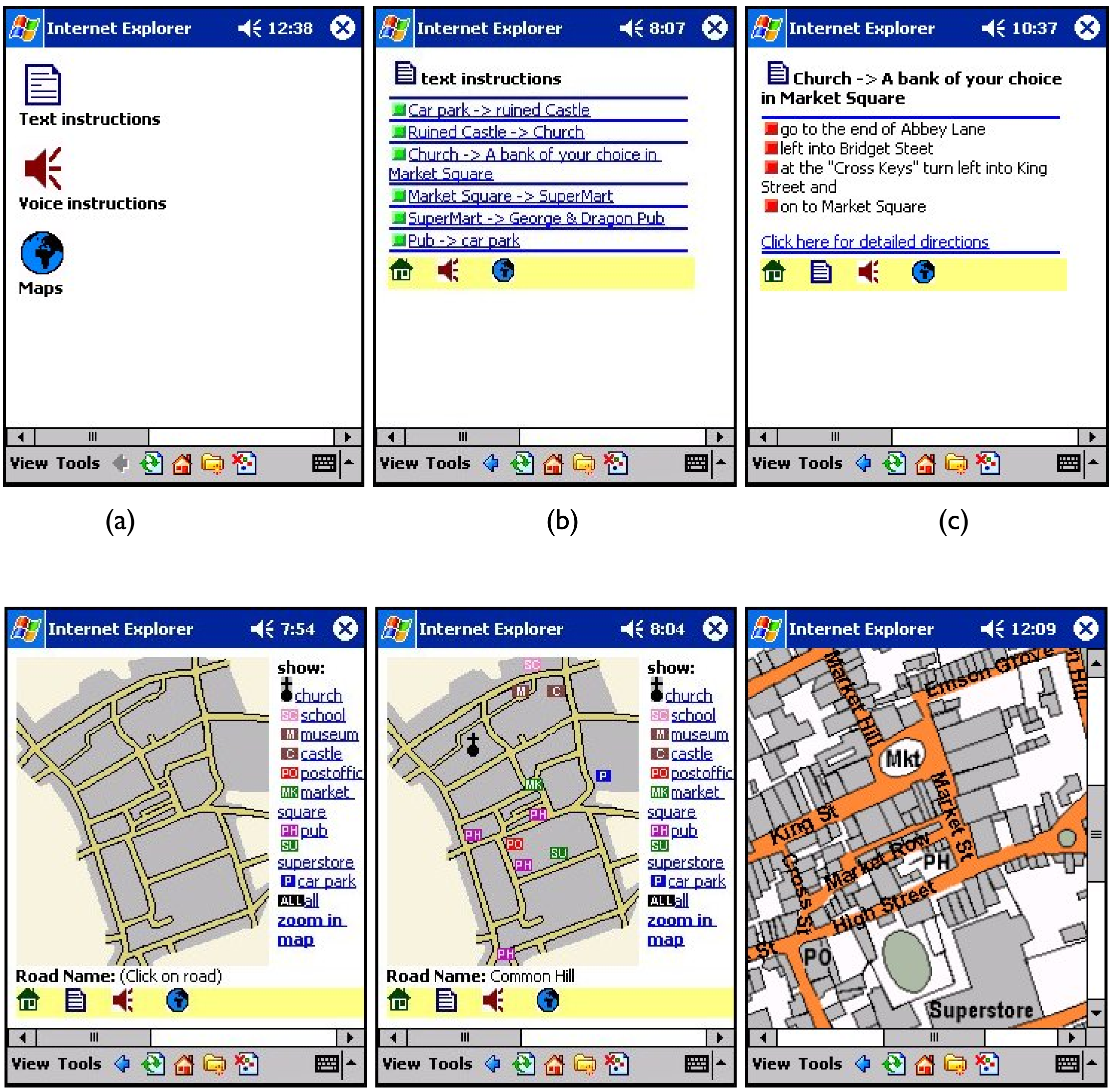


Figure 6.9 The structure of web pages with its hyperlinks as installed in the in PDA (upper levels of hierarchy only).

Currently, some basic guidelines should be considered when designing Web page content and style for mobile devices (Chu, 2002). The screen size of mobile devices is small – approximately 100x120 pixels for most mobile phones (some of the latest models have slightly larger screen sizes) and 240x360 pixels for palm PDA. Thus there are quite severe constraints upon display of content using small screens. Therefore, the focus for displaying information on the PDA is upon presenting essential information content with an adequate level of readability and providing easy navigation through the pages. Furthermore, it was necessary to devise an appropriate trade-off between the number of levels in the page hierarchy and the content of each page. A table of content style was used here for the start page incorporating icon and text alternatives. The icon bar for navigation was shown on each page at all levels (see Figure 6.10). Scrolling bars were avoided, except for the zoomed map level. Figure 6.10 (a) shows the simple layout of the table of content page with both icon and text. Figures 6.10 (b) and 6.10 (c) illustrate some example pages for text and voice modes of communication respectively, whilst Figures 6.10 (d) (e) and (f) display the area with maps. In detail, Figure 6.10 (d) shows the sketch map of the urban setting U2 with a clickable landmarks list on the right and road name option on the bottom of the page. Figure 6.10 (e) shows the same sketch map on which all the landmarks are displayed, also with the name of the road that was clicked. Figure 6.10 (f) shows a part of the detailed map which was zoomed in from the sketch map page. For the setting U1, the format and style of interface is exactly the same. See Appendix IV for more example pages for both settings. There was a total number of 78 web pages with 39 images created for setting U1, 79 web pages with 41 images for setting U2.



(a) (b) (c)

(d) (e) (f)

Figure 6.10 Sample pages of information content from the PDA.

6.2.3 Test environment part 3 – multi-source data collection method

The third component of the test environment is a series of software for capturing individuals' interactions and information transactions in completing wayfinding tasks. A multi-source data collection method was established in the test environment which is able to capture and integrate spatio-temporal data of individual position/location within the environment, data on information access via the mobile device and data on individual overt behaviour. This was to ensure that adequate data could be collected with which to analyse the interactions. The data were recorded through a combination of automated and semi-automated means, which included:

- movement tracking data;
- information access and usage data via PDA;
- individual actions and reactions data through observations.

An individual's location within the VR model can be tracked as spatial data with a time attribute stamp through the VR system. Within the test environment, the movement of individuals can be recorded through a tracking device linked to the Intersense IS900 system. Each individual's entire route through the VR model can thus be collected in a time-location format of (X, Y, t,). Head height and head movements are also recorded through the tracking device in a format of (Z, pitch, yaw, roll) along with each time-location record. This part of the data capture can be performed automatically once every second by the system. As shown in Table 6.3, two sets of position data (X, Y, Z, Pitch, Yaw, Roll) can be recorded along with the time when individuals move through the VR environment. The set (X_t, Y_t, Z_t, Pitch_t, Yaw_t, Roll_t) records the actual position in the VR Lab (t denotes 'test' in the VR system) where individuals physically stand or move, but which is not used in this research. The set (X_w, Y_w, Z_w, Pitch_w, Yaw_w, Roll_w) is the position data in the VR environment (w denotes 'world'), which formed the movement tracking data. The exact position of an individual at any time could then be provided through this detailed tracking data. The route that each individual took and the time used for completing each task could subsequently be derived. The time and location of each interaction with the PDA could also be determined from this data set. In addition, the data on head movement could be used to get extra data on when individuals are using the PDA for information and to assist in analysing what individuals are observing in the test environment for future research.

Time in second	Position in VR environment			Head movement in VR environment			Position in VR lab coordinates			Head movement in VR lab coordinates		
Time	X_w	Y_w	Z_w	Pitch_w	Yaw_w	Roll_w	X_t	Y_t	Z_t	Pitch_t	Yaw_t	Roll_t

Table 6.3 The track data structure.

In order to record the information accessed through the PDA and the format in which it is accessed, a set of software was designed and programmed for the PDA. The data on usage of the PDA, can be divided into three main categories: the type of information accessed, the mode of communication used and the time at which the information was accessed. By using a Web browser as the user interface, as discussed in §6.2.2, a set of Cookies was written to record which Web page was being accessed and at what time. Thus, referring to the structuring of the Web pages as previously described (Figure 6.8), it is possible to use the Cookie data files to identify what information was being accessed, at what detail and by which mode. Cookie functions were written using JavaScript and embedded in each Web page. The main function of the Cookies was to record the accessed Web page name, as well as the access time with hour, minute and second. Also when the same Web page was accessed again, the cookie was programmed to capture the time again with a flag showing repeated access. Figure 6.11 shows the structure of a Cookie. Each time that a Web page was activated, a record was written into a corresponding Cookie data file. For establishing a sequential record of the information accessed via the PDA throughout a session in the test environment, the Cookie data files could be combined and sorted by time attribute. This sequential record could also be formed for each individual, showing the progress in wayfinding activity in relation to individual information usages and preferences, for example the most used mode of communication, the level of detail required and the frequency of access. The spatial location of where the information was accessed using the PDA could be derived by integrating the data from the Cookies with the movement tracking data (for details see Chapter 8).

```
function getCookie (name) {
/ retrieve relevant cookie file for write data into it
}

function setCookie(name, value) {
  / save data such as accessed web page name and the access time into cookie file
}

function deleteCookie (name) {
/ delete a cookie
}

function recording (name) {
  / record the name of the Web page and the access time (hour, minute and second)
   when the content of a Web page is accessed first time.
  / record the access time (hour, minute and second) with repeat access flag
  when the content of a Web page is accessed again
}
```

Figure 6.11 The structure of the Cookie.

In addition to these automated measurements, additional data pertaining to participant behaviour was collected through direct observation. These observations included: noting when and where participants got lost or needed to ask for help; the completion time of individual tasks; any rotation of the PDA in the hand (as if turning the map around); and looking at PDA. Participants were encouraged to speak aloud their thoughts and feelings as they progressed through the tasks. Observations of the participants were recorded by the investigator through a semi-automated method using an interface to Access. Using Visual Basic Application (VBA), an observation recording program with a user-interface (Figure 6.12) was programmed with clickable buttons to record observations into an Access database. By clicking a button on the interface, the relevant action stated on the button was recorded into the database table along with the time of recording. This interface was structured around five broad classes of observations. The first group concerned aspects of performance such as start time, task completion, asking for help and so on. Second, there were observations relating to the use of PDA such as looking at it or rotating it. The next two groups concerned details about movement and any apparent confusion and disorientation. Specific movement-related observations included recording whether participants were looking for a street name or specific landmarks. The final group concerned indicators of confidence and any onset of motion sickness (requiring the participant to take a rest). Such motion sickness can affect users of immersive VR. The recorded observation data saved in the Access database files were exported for integrating with other experiment results. Whilst some of these observations entail subjective classification, they nevertheless provide valuable contextual information to supplement automatically collected data and assist in interpreting a participant's overall performance. Because the experiments were carried out in the test environment, recording of observations by the investigator could be more discrete and consistent without interrupting and distracting participants as would likely be the case if carried out in a real world environment.

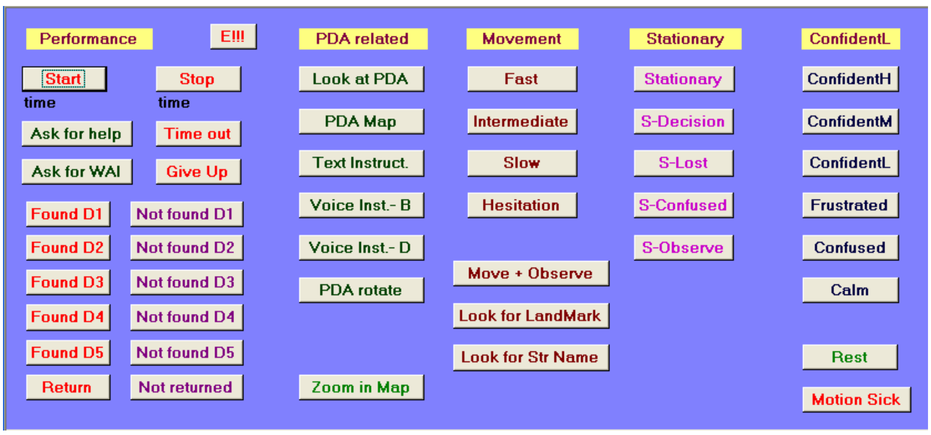


Figure 6.12 The database interface for recording observational data.

By using the multi-source data collection method, the three data sets - movement tracking, information accessed through PDA and participant action and reaction – could be collected automatically and semi-automatically throughout the wayfinding experiments. These data sets together provided facets of a comprehensive picture that could be used to study the behaviour and interaction between individuals, mobile devices and the environment.

6.3 Post-experiment questionnaire

The post-experiment questionnaire was constructed in two parts, in order to assemble data on the feedback from participants following the experiments. The complete questionnaire of part 1 and part 2 are given in Appendix V.

Part 1 of this questionnaire was designed to be carried out by participants immediately following completion of the first set of wayfinding tasks in one of the settings. This part of the questionnaire contained two different sections. Within the first Section, all questions were set up in relation to participant feedback on their experience in the urban VR models, such as their sense of "being there" and their experience in VR urban models in comparison to experiences in real towns. These questions were compiled based upon similar questions used for studying sense of presence in immersive virtual environments (e.g. Usoh *et al.*, 2000; Slater *et al.*, 2002). Importantly, two more questions were specifically created in order to elicit participant feedback on their wayfinding behaviour in VR urban environments. One question concerned whether or not respondents felt that they used a similar manner / approach to find their way in these virtual environments as they did in the real world, whilst another sought to ascertain whether they used similar features to find their way around in these virtual environments as they did in the real world. Each of these questions was designed as structured tick box questions with a six point rating scale from 'strongly agree' to 'strongly disagree'. In addition, two semi-structured questions on the same topic were provided to allow participants to list any specific factors that gave them a sense of 'really being' in the street or that pulled them away from 'really being' in the street. The second Section of part 1 of the questionnaire was designed as a series of open-ended questions, which requested a list of features remembered, recall (if possible) of the route and a sketch map with landmarks for the area with the route they took. The data collected using these methods were intended for subsequent analysis along with the data collected during the actual interaction process in completing wayfinding tasks.

In a similar way to part 1, part 2 of the post-experiment questionnaire was designed to be completed after participants finished the second set of wayfinding tasks in another setting.

The two same questions, as in part 1, about participant feedback on wayfinding behaviour in urban VR environments were used again in order to assess the consistency on this important aspect. Other questions were compiled relating to PDA usage in both wayfinding experiments, such as usefulness of information (maps, text and voice) for wayfinding, and the ease of using the PDA. Also open questions were designed for participants to write down if and why they found the PDA difficult to use if this was the case, what improvement would be useful and what additional information could usefully be provided by the PDA. In the next Section of the post-experiment questionnaire part 2, participants were requested to describe the route taken if they could and to draw a sketch map with landmarks for the area with the route they took. Finally, a short interview was carried out in an informal conversation style. The main purpose of this debriefing interview was to confirm that all questions had been understood and answered. One of the emphases was upon participant feedback on describing their actions and behaviour in VR in comparison with their normal wayfinding behaviour in the real world, particularly with regard to information requirement preferences and strategies adopted in order to complete wayfinding tasks.

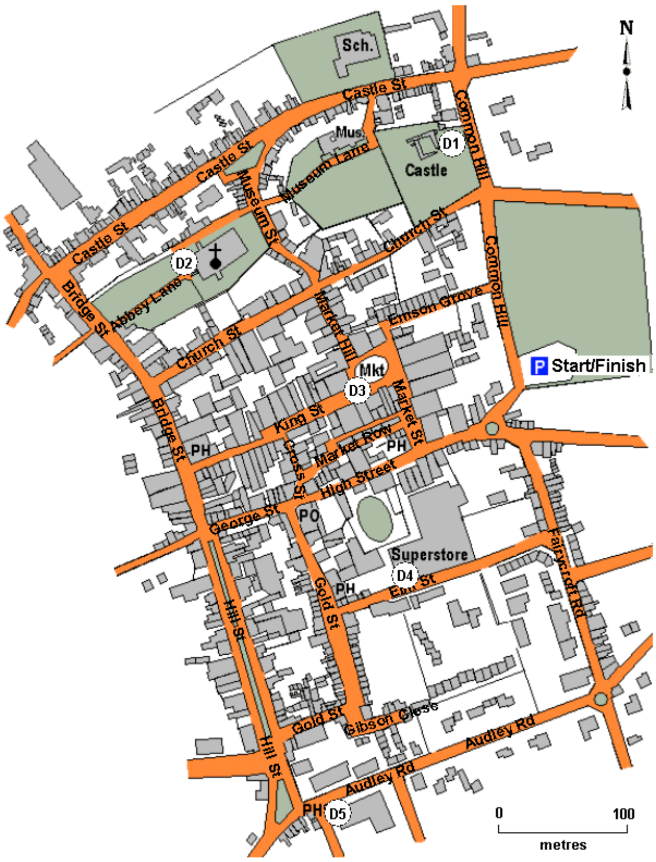
6.4 Design of the wayfinding experiments

Having set up the test environment as well as the pre-experiment and post-experiment questionnaires, a wayfinding experiment was designed in order to collect a range of data with the focus on the interaction and information transactions between individuals, devices and environments. The whole wayfinding experiment was designed in four main parts: completing a pre-experiment questionnaire, undergoing a training session, carrying out two sets of wayfinding tasks and completing post-experiment questionnaires along with an informal interview. The pre-experiment questionnaire was set up for participants to complete prior to on-site experiments. The wayfinding experiments were designed for each participant to carry out wayfinding tasks in both urban setting U1 and setting U2. The two settings were modelled in virtual environments as discussed early in §6.2 this Chapter. For the experiments, these two urban models were then implemented in an immersive projection technology VR lab, the CAVE (Cruz-Neira et al., 1993). Post-experiment questionnaires were set up to be completed immediately after each set of wayfinding tasks whilst the informal interview was planned to be conducted after the experiments.

For the two different urban settings, two specific sets of wayfinding tasks were designed. In setting U1, the complete wayfinding task was to begin at a car park and to find five different destinations (a modern church, a post office, a McDonald's, a cinema and a monument) sequentially before returning to the car park as the finishing point (Figure 6.13 (a)). The design for each successive destination of the wayfinding tasks was intended to entail a growing level of complexity in terms of length of route, numbers of turnings, and number of choice points passed. For example, the first wayfinding task was from the car park to the modern church at destination D1 and entailed following a fairly straight road out from the starting point and only contained one obvious turning towards D1. The subsequent tasks were designed to incorporate an increasing number of turnings, junctions and/or roundabouts along the routes. However, in setting U1, the layout of the area was grid-like, therefore some routes in the later tasks might not have appeared to be more difficult than others. To keep the experiment consistent, the set of wayfinding tasks for setting U2 were designed in a similar way. In setting U2, the complete task was also to begin at a car park and to find five different destinations (a castle, St Mary's Church, the Market Square, a superstore and the George & Dragon pub) sequentially before returning to the car park as the finishing point (Figure 6.13 (b)). The wayfinding task for each destination was designed in such a way that the route for reaching each destination would become increasingly complicated. For instance, the first wayfinding task was from the car park as the starting point to the castle as destination D1. The route was a straight road with a left-right choice outside the starting point and two junctions along the route. As for the third wayfinding task from the Market Square D3 to the superstore at destination D4, the route not only contained a number of turnings, but also started at the square with a choice of four roads with which to proceed.

In both wayfinding tasks, all routes selected between two destinations for the text and voice instructions were chosen based on the easiest to follow in comparison with other choices. Also the routes chosen avoided roads already travelled along in order to avoid only a few routes being used during the experiments. These were subjective judgements. The maximum walking speed was set as 4.4 meters per second, slightly faster than normal walking speed. This was tested and arrived at after a number of test runs (see §6.5.3). This was the maximum speed which could be reached by participants. Participants could control the speed up to the maximum or proceed as slowly as they liked. This maximum walking speed was kept the same for both settings.

(a)



(b)

Figure 6.13 Two urban settings with wayfinding task destinations: (a) urban setting U1; (b) urban setting U2.

Another important aspect in designing these wayfinding experiments focused upon accessing the information by participants for assisting them in completing tasks. In §6.2.2, the structure and the communication modes used for the information content have been discussed. The information accessed through a PDA can be route instructions (in either text or voice mode) and different levels of map representation. Two options were considered for accessing the information from a PDA: assigning participants into groups before experiments with different restricted information for each group (e.g. a group of participants using route instructions only, whilst another group using maps only); free choice for all participants to choose the type of information they preferred. The first option might result in bias if, for example, text were imposed upon participants with strong preferences for map use or vice verse. Therefore, 'choose information as you prefer' approach was used to explore information preferences during actual wayfinding tasks, instead of assigning participants into groups before the experiments. During the experiments, participants were allowed to choose any information available from the PDA depending on their preference and needs in completing wayfinding tasks. There were no restrictions upon what type of information could be accessed through the PDA and in which communication mode it was conveyed. In addition, no limit was set on the number of times that the information could be accessed.

All participants were treated as a single group to carry out both sets of wayfinding tasks in two urban settings U1 and U2. The approach adopted followed the principle of within-subject design instead of between-subject design (Spector, 1981), although not a strict factorial design. Firstly, with a consideration of idiosyncratic differences between individual participants, particularly on their spatial ability with underlying characteristics such as gender and ethnicity, there would be difficulty in assigning participants into different groups randomly. This would be even more difficult in this research, because the number of participants was not a large sample size because of the limitations of time and resources. These included the budget of using the VR lab and the time of PhD duration. Therefore, both sets of prescribed wayfinding tasks were required to be completed by all participants, one within each of the two different settings assisted by information provided through a PDA. The order of the two settings used in the experiment was alternated according to the concept of counterbalance. Thus half of the participants started their first set of wayfinding tasks in setting U1 and the half started in setting U2, allowing one to offset the other and to be able to study any learning effect.

A number of elements were designed to be held constant in the wayfinding experiment. For the wayfinding tasks in both settings, all the destinations were kept at the same locations and in the same order of completion for all participants. Therefore participants would all visit the same destination locations which would put them on an equal footing to develop their knowledge of the areas. This was further underlined by providing unfamiliar test settings for all participants. Furthermore, a range of information for assisting the wayfinding tasks was provided to all participants. For the last leg of wayfinding tasks in both settings, the experiment was designed in such a way that all participants were provided only with map information (no route instruction available in either text mode or voice mode). The information available for this final task was thus also kept at a constant level. This simulated situation, in which maps were the only available information, could be considered as a control factor in terms of information usage.

The implementation of the entire wayfinding experiment was organised into six sequential sections. The first section entailed a pre-experiment questionnaire (Appendix II), which was required to be completed prior to the on-site experiment. There was also information accompanying the questionnaire explaining the whole experimental procedure, its broad objective, the nature of the experiment VR site and the equipment used. The second section, as a part of the on-site experiment, was a training session before the main experiment that was used in order to familiarise participants with the virtual environment and with the PDA. Following the training session, the third session was a prescribed set of wayfinding tasks to be carried out in either setting U1 or setting U2 (Figure 6.13 (a) and (b)). Post-experiment questionnaire part 1 (Appendix V) was the fourth part of the experiment which was used immediately following the first set of wayfinding tasks. The fifth part was another set of wayfinding tasks that was to be carried out in the alternative setting. As the sixth part of the experiment, post-experiment questionnaire part 2 (Appendix V) was completed along with a short informal interview after participants finished the second set of wayfinding tasks. During the wayfinding experiment, participants were encouraged to speak aloud their thoughts and emotions. The detail of the conduct of the experiment will be discussed in Chapter 7.

6.5 Testing the design

The design and the setting of the experiment were tested in two parts: the questionnaires; and the test environment.

6.5.1 Testing the questionnaires

The principal objective of the pre-experiment questionnaire was to see whether the questions could differentiate different groups of people in term of their spatial abilities. The testing of the questionnaire served as a means of identifying those elements that may need to be modified (see §6.1). The pre-experiment questionnaire was trialled on 89 participants from a wide range of age groups and backgrounds. The participant age ranges were from 18 to over 60. The percentages of respondents in the 30's age group, 40's age group and 50's age group were 14%, 27 % and 6.7% respectively, with 47.2% of them under 30. 40% of respondents were female and 60% male. 50.6% of participants were academics/students from the disciplines of Geography, Surveying, GIS, Planning and Biology. The remaining 49.4% of participants came from a wide range of backgrounds including residents of a town outside London and its surrounding areas, and people working in London and Bristol. For the results from all 21 questions, Ward's (1963) method with Euclidean distance was used to classify participant spatial ability and spatial awareness (see Chapter 8 for details). From Figure 6.14, it is evident that there is considerable linkage distance between three broad groups G1, G2 and G3 regarding the 21 variables (questions). G1 can be interpreted to have low score responses to the questionnaire. G2 have the highest scored responses whilst G3 have better than average scores. A t-test on average scores per question showed significant differences between all three groups ($p < .001$). The analysis of the questionnaires will be discussed in Chapter 8.

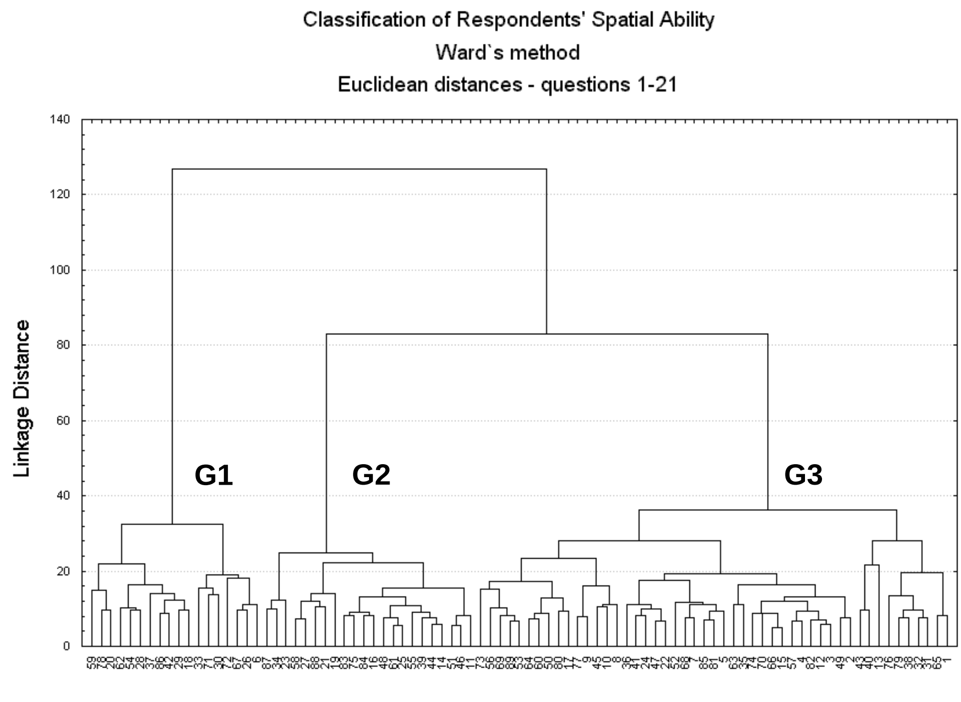


Figure 6.14 Classification tree based on participants' spatial ability using Ward's Method.

The subsequent modifications to the initial questionnaire (Table 6.1) may be summarised as follows. Questions Q4 and Q5 on the sense of direction in aspect A1 were originally set up to ascertain individual thinking about the surrounding environment in terms of cardinal directions: one emphasising a natural open environment, the other emphasising a familiar environment such as their home town. From the results, participants tended to answer both questions in the same way. In addition, the responses showed that these two questions were highly correlated (Spearman's rho 0.68, $p < .001$). Therefore Q4 and Q5 were combined into a single question Q4 (Table 6.2) concerning the general environment. For questions Q6 and Q7, the aim was to differentiate people with preference of image thinking from people with verbal thinking. However, the responses indicated that these two questions were not significantly correlated (as opposed to an expectation of a strong negative correlation). From responses, this could have arisen either because people think they have both image and verbal thinking, or because image thinking could be construed to include images of landmarks and images of maps – thereby giving rise to some confusion. These two questions were therefore deemed ambiguous and were removed. For the Q13 in aspect A7 on map use, the responses showed no distinct differences between participants. The other two questions, Q11 and Q12 in A7 proved better indicators of map use. Therefore, Q13 was removed. Regarding Q16 in aspect A8, over 91% of respondents agreed that there was no confusion between right and left turns and therefore this criterion did not appear to differentiate any characteristic amongst the participants. It may be the case that very few participants did confuse left and right turns. Or perhaps even though people do confuse left and right turns, they tend not to recognise it when answering the question. Nevertheless, Q16 was removed. For testing the post-experiment questionnaire part 1 and part 2, a further nine volunteers took part in completing two sets of wayfinding tasks in the corresponding setting U1 and U2. They completed both parts of the questionnaire after the completion of wayfinding tasks. No difficulty was reported and a short informal interview in a conversation style was found to be welcome and was informative for the investigator. None of these nine participants was included in the wayfinding experiment conducted later because of their acquired experience and knowledge of the urban settings.

6.5.2 Evaluating the test environment

Tests were carried out on the running of the VR models, the functioning of the PDA for providing wayfinding assistance and the functioning of the software for multi-source data collection. The focus of this evaluation was upon the design and technical functioning of the test environment.

With the priority of smooth running of the VR models with natural street views, the first test was carried out to run both models in the VR lab (see §7.3 for detailed description of the laboratory setting) in the Department of Computer Science, UCL. This process was assisted by the lab manager, Dr David Swapp. In the first stage, both models were run only with their object geometry and without their photo-realistic textures. Both object geometry models were found to run smoothly, in their entireties, with a fast response. Therefore, no further generalisation was required on the geometry of the objects. In the second stage, the two models were run with all their photo-realistic textures. For urban setting U2, there were 17.5Mb of image files for texturing. This model did not load successfully. Although the texture memory limit for the SGI machine is 64Mb, the image files, saved as either as jpeg or gif, did not provide a reliable indication of the actual memory space required to present the images. The actual size of the total images used was thus too large to run the model in the system. As a consequence, a set of test trials on reducing the vista range were carried out. With a vista range of 100 metres the model ran smoothly. However, the view in a straight line direction then had only a100 metre vista range and did not appear realistic. With an increased vista range as 200 metres, the model ran smoothly in a straight line, but responded very slowly when encountering more than 45 degree turns: this was not acceptable for the experiment purposes.

Therefore, as discussed in §6.2.1, in order to maintain longer vistas, another option was to systematically reduce the resolution of the photographic images used without seriously compromising the model's realism. A series of test runs was conducted. Firstly, only images with file size less than 100K were included in the model and the performance was found to be smooth. For these, the total file size of texture images was 1.5Mb. Next when the model was tested including all images with file sizes less than 150K, the performance was acceptable. The total size of texture images used was 5.25Mb. According to this guideline, the resolution of the photographic images used for texturing was reduced by a proportional amount on the basis of retaining acceptable visual quality. The number of pixels used in the images was also constrained to a power 2 series in order to optimise the processing speed for the VR system. The model was tested again with these images. It ran smoothly and responded fast, with very similar levels of realism to the full sized images (see Figure 6.15). The total file size of images used for texturing this model was 4.84Mb. The same tests and adjustments were applied to urban setting U1. Here the total file size of images used was reduced from 6.48Mb to 3.62Mb. The performance of the revised model was comparable to that of model U2.


(a)


(b)

Figure 6.15 Reduction of image resolution, an example from setting U2: (a) original image: 738 by 738 pixels; (b) reduced resolution: 256 by 256 pixels

The walking speed in the VR models could be controlled by participants from as slow as they desired up to a maximum of walking speed. The maximum walking speed was initially set as 2.2m per second (7.9 km per hour), which would be considered as a fast walking speed in the real world. Three volunteers were invited to complete the two sets of wayfinding tasks in both urban settings in the VR lab. From the general feedback, the maximum speed was considered to be too slow, and was perceived to be much slower than a walking speed in the real world. This was particularly obvious on long straight stretches of road. As each individual could decide when to reach the set maximum speed and there was no physical tiredness involved, the maximum speed could be increased. As a further consideration, a low maximum speed would cause longer time in the VR lab in completing wayfinding tasks, which could result in more participants suffering from 'motion sickness'. In consideration of such feedback, the maximum speed was therefore doubled to 4.4m per second (10 mph). This maximum speed was tested again. The volunteers were more satisfied with the maximum speed with which they could reach, but still felt it equated to normal walking speed.

Another test on the VR models was to check the consistency of scenes from street viewpoints. Two volunteers, who were both familiar with VR and handling with computers, were invited to inspect exhaustively for consistency of scenes and completion of objects in all models. The two volunteers 'walked' through every street in both urban models and the model for the training session; all models were run on-screen. Every façade of all objects (e.g. buildings) visible from street viewpoints was checked. Any reported façades without realistic photo images were then textured. Furthermore, the consistency of street signs was also inspected, with particular regard to any missing street signs and the consistency of the style. The names on street signs were also checked to make sure that they corresponded to the street names shown on the maps. Improvement was thus made for the final version of the VR models.

The wayfinding assistance provided by a PDA was tested in two aspects: the completeness of the information and any difficulties experienced in PDA use. In the first stage of testing, two volunteers were invited to access all instructions in both text and voice mode via the PDA, and to 'walk' in the VR models (on-screen) following the instructions. The maps were also tested by accessing all options such as zoom-in maps, sketch maps with different landmarks and road names displayed. Any missing and incorrect information was recorded and then amended. There was no report on any difficulty in using the information provided. In the second stage of testing, nine volunteers took part in completing the two sets of wayfinding tasks in both urban settings. The VR models were implemented on a large projected screen instead of in the VR lab as the available grant for using the VR lab could only cover the time for the final experiments. During these tests, the investigator was available to record any problems and feedback given. Any incorrect/missing information was recorded. Further minor modifications were thus made. Regarding the difficulty encountered in using the PDA for accessing the information, it was recorded during the tests and the subsequent interview. Only two concerns were raised in using the PDA: difficulties in using the stylus to click the screen, and the need to use reading glasses coupled with a stronger back light for some individuals. A more clear instruction for using a stylus to click relevant items was then built into the training session. It was also noted in the test procedure that participants should be invited to adjust the back light according to their needs before commencing the experiments.

Finally, tests were carried out on the multi-source data collection method. The recording of location (x, y, z) within the VR models was tested at the same time as three volunteers were tested for walking speed (see above). The tracks, derived from (x, y) coordinates, were plotted and overlaid with the area maps, which were found to precisely represent the routes walked after a simple shift transformation to real world co-ordinates. The z value correctly recorded the eye-level height. The recording frequency was adjusted from once every 0.1 second to once every second to avoid unnecessary large files. For recording the information access and usage via a PDA, the test was carried out while conducting the test for wayfinding assistance information provided on nine volunteers (see the previous paragraph). The data recorded through a set of Cookies were exported from the PDA and sorted by time sequence. The data were then compared with the actual access log recorded by the investigator. The results showed that the set of recordings for this purpose was working correctly. It was noted that there was limited storage capability for each Cookie data file. Therefore, it was decided that the recorded data files would be downloaded when participants took rests during the experiments instead of downloading all data files when the entire experiment was finished. Furthermore, the interface and the program for recording participant action during the wayfinding tasks were tested. The observation data were recorded correctly into the database tables in Access. The interface was improved by re-arranging some of the action buttons for convenience of use. Buttons to record rest periods and the onset of any motion sickness were added to record these events.