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September 1998
Think-aloud protocol and heuristic evaluation of non-immersive, desktop photo-realistic virtual environments

Rochelle de Asa Villanueva

A thesis submitted for the degree of Master of Science at the University of Otago, Dunedin New Zealand

22 July 2004
Abstract

The concept of Virtual Reality (VR), a three-dimensional, computer-generated environment that allows for a single or multiple users to interact, navigate, respond, and experience a synthesized world modelled from the real world, has provided social, scientific, economic and technological change since its inception in the early 1960’s. Since that time, VR has also evolved into many forms and taken different tangents. One form that it has taken is non-immersive desktop photo-realistic Virtual Environments (VEs), where real-world still images are joined together to create 360 degree panoramas of places and objects in time. The concept has become increasingly popular since its creation using Apple QuickTime Virtual Reality Authoring Studio (QTVRAS) in 1995.

This study is about the evaluation of non-immersive desktop web-based photo-realistic virtual environments using a previously applied evaluation method for non-immersive desktop 3D multi-user environments conducted by Koykka, Ollikainen, Ranta-aho, Milszus, Wasserroth and Friedrich (1999). The two qualitative evaluation methods are think-aloud protocol analysis and heuristic evaluation. There are three aims in this study: (1) to determine whether applying the same usability evaluation methodologies result in additional usability guideline categories: 3D environments should provide support for orientation, navigation and movement, real world metaphors need to be clearly understandable and avoidance of delay and waiting periods in performance (identified from the Koykka et al. study); (2) to determine whether think-aloud protocol or usability heuristic evaluation is a better evaluation method for identifying usability problems in desktop, photo-realistic virtual environments; and (3) to determine whether large-scale desktop, photo-realistic virtual environments will have more
Abstract

usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments.

It is hoped that by investigating these aims that design guidelines for desktop, photo-realistic virtual environments may be derived.

Twelve subjects took part in evaluating two different web-based photo-realistic VEs using the Think-Aloud Protocol (TAP) and Jakob Nielsen's usability Heuristic Evaluation (HE). The think-aloud protocols were videotaped and the heuristic evaluation results were word-processed. A variation of the grounded theory research method called Emergent Themes Analysis (ETA) was used to "distil" the recorded narratives into broad themes.

The results show that ETA derived four broad themes: functionality, interaction, appearance and user comments. Within each broad theme, sub-themes were also derived to produce possible design guidelines for desktop, photo-realistic virtual environments. The results also show that the functionality and interaction broad themes were similar to the categories suggested by Koykka et al. (1999). Furthermore, the results indicate that small-scale non-immersive, desktop, photo-realistic virtual environments had more usability problems than large-scale non-immersive, desktop, photo-realistic virtual environments, contrary to the hypothesis that large-scale VEs will have more usability problems due to its complexity.

Using the ETA method to analyze the data, the think-aloud protocol derived more themes compared to the heuristic evaluation – suggesting that TAP is a better usability evaluation method than HE in this type of study. However, a combination of the two qualitative methods has identified a greater number of usability problems, supporting the need for triangulation of research methods.

It is hoped that these new design guidelines will allow for more usable design of non-immersive desktop, photo-realistic virtual environments. Furthermore, it is hoped that this study provides a beginning of future developments of usability evaluation methods for non-immersive desktop, photo-realistic virtual environments. Regardless of its future use, usability evaluations of any virtual environments are still needed.
Preface

This section briefly explains my interest in this study and acknowledges the contributions that various people have made to this piece of research.

I've been involved in making QTVR panoramas in an on-and-off basis for the last eight years, some for interest but mainly it fulfilled some sort of need. When Dr. Hank Wolfe, from the Information Science Department, asked me to create a series of panoramas of the AsiaCrypt 2000 conference location in Queenstown, I jumped at the chance. My experience with that project allowed me to submit a poster for OZCHI 2001, an internationally refereed conference, which I attended.


There are many people that I would like to acknowledge in this thesis. They are as follows:

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When I first wrote this acknowledgment, I perhaps wrote it a little too prematurely. I started writing this when I was doing the first draft of my literature review (April 2003). Procrastinating as you can see. Three years is a long time, if you think about it. Well, four years and a month to be exact. A lot of things happened, that may seem insignificant at the time, but are in actuality, quite significant. So here is my big thank you to the people who have significantly (although it may seem insignificant to others) contributed to this piece of work.
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Finally, but most importantly, I wish to thank God for the inspiration and the motivation. I always pray for it, and somehow, I always get it.
# Table of Contents

Abstract ......................................................................................................................... i
Preface ........................................................................................................................... iii
Table of Contents........................................................................................................... v
Table of Tables............................................................................................................... x
Table of Figures.............................................................................................................. xii
Table of Abbreviations................................................................................................. xiv

Chapter 1 Introduction ................................................................................................. 1
1.1 Background and Research Objectives and Aims ................................................. 1
1.2 Structure of the Thesis ......................................................................................... 2
1.3 Chapter Summary ................................................................................................. 4

Chapter 2 Virtual Reality Technology ....................................................................... 5
2.1 Introduction ........................................................................................................... 5
2.1.1 Overview of Virtual Reality ........................................................................... 5
2.1.2 Virtual Reality, Virtual Environments, Virtual Worlds, Cyberspace .......... 6
2.2 Virtual Reality Technology .................................................................................. 6
2.2.1 Immersive versus Non-Immersive Virtual Reality Systems ...................... 7
  2.2.1.1 Non-Immersive Desktop VR – Virtual Reality Modeling Language (VRML) 8
  2.2.1.2 Non-Immersive Desktop VR – Apple’s QuickTime™ Virtual Reality (QTVR) 10
2.3 Applications of VR .............................................................................................. 12
  2.3.1 Travel and Cultural Heritage ....................................................................... 12
  2.3.2 Visualization Applications ........................................................................... 13
  2.3.3 Medical Applications ................................................................................... 14
  2.3.4 Training Applications .................................................................................. 15
  2.3.5 Education ..................................................................................................... 16
  2.3.6 Recreation and Entertainment ..................................................................... 17
  2.3.7 Sales and Marketing Applications ............................................................... 18
2.4 Chapter Summary ................................................................................................. 18

Chapter 3 Qualitative Research Methods ................................................................. 19
3.1 Introduction .......................................................................................................... 19
3.2 Qualitative Research Methods ............................................................................ 19
  3.2.1 Grounded Theory ....................................................................................... 20
  3.2.2 Action Research ......................................................................................... 21
Table of Contents

5.3.1 Usability evaluations of VRML-based virtual environments .................................. 49
  5.3.1.1 Theoretical models of interactions ......................................................... 50
  5.3.1.2 User-related design issue ........................................................................ 51
  5.3.1.3 Experienced versus Novice GUI users ...................................................... 51
  5.3.1.4 VR Guideline Questionnaires .................................................................... 51
  5.3.1.5 Wayfinding in Large 3D Virtual Worlds .................................................... 53
5.3.2 Usability evaluations of VRML-based and QTVR virtual environments .................. 53
  5.3.2.1 Task performance, navigation and subjective satisfaction ......................... 53
5.3.3 Usability evaluations of QTVR virtual environments .......................................... 54
  5.3.3.1 Hotspot feedback, detailed help ............................................................... 54
  5.3.3.2 Eight Activity Breakdowns ....................................................................... 55
  5.3.3.3 Natural and logical navigation, hotspot size and location ....................... 55
5.3.4 Complexity of Information Systems .................................................................... 56
5.4 Chapter Summary ..................................................................................................... 57

Chapter 6 Research methods used in this study ......................................................... 58
6.1 Introduction ............................................................................................................ 58
6.2 Implications for the current study ......................................................................... 58
  6.2.1 Heuristic Evaluation ..................................................................................... 59
  6.2.2 Think-aloud protocol .................................................................................... 62
  6.2.3 Emergent themes analysis ............................................................................ 63
6.3 Chapter Summary ..................................................................................................... 66

Chapter 7 Experimental Methodology ......................................................................... 67
7.1 Introduction ............................................................................................................ 67
7.2 Experimental Design ............................................................................................. 68
  7.2.1 The Virtual Environment (VE) systems ....................................................... 69
  7.2.2 Ethical Approval ......................................................................................... 71
  7.2.3 Participants .................................................................................................. 71
  7.2.4 Web Environment ....................................................................................... 71
7.3 Phase One: Evaluation of non-immersive, desktop, web-based photo-realistic VEs using think-aloud protocol ................................................................. 71
  7.3.1 Equipment and Environment ....................................................................... 71
    7.3.1.1 Digital Video Cameras and Tripods for keystrokes, mouse movement and speech ........................................................................................................... 71
    7.3.1.2 Stop watch to gauge exploration and task completion times ................ 72
    7.3.1.3 Using the VE system equipment and environment for Phase One: Think-aloud protocol ........................................................................................................ 72
    7.3.1.4 Task Sheets Design ................................................................................ 72
    7.3.1.5 Participant Consent and Briefing ............................................................ 73
  7.3.2 Think-Aloud Protocol Procedure ................................................................... 73
    7.3.2.1 Initial Briefing ....................................................................................... 73
    7.3.2.2 Exploration Stage ................................................................................ 74
7.3.2.3 Task Performance Stage ........................................................................... 74
7.3.2.4 Interview Stage ...................................................................................... 74
7.3.2.5 Debriefing Stage .................................................................................... 75

7.4 Phase Two: Evaluation of non-immersive, desktop, web-based photo-realistic
VEs using usability heuristic evaluation ................................................................. 75
7.4.1 Equipment and Environment ..................................................................... 75
7.4.1.1 Heuristic Evaluation Procedure ............................................................. 76

7.5 Chapter Summary ......................................................................................... 77

Chapter 8 Experimental Results ......................................................................... 78
8.1 Data Analysis with Emergent Themes Analysis Approach .................................. 78
8.1.1 Procedure ................................................................................................. 78
8.1.2 Deciphering the results table ..................................................................... 80
8.1.3 Results Presentation .................................................................................. 82

8.2 The Results ................................................................................................... 82
8.2.1 Section 1: Within Groups .......................................................................... 83
8.2.1.1 Think-Aloud Protocol Evaluation ......................................................... 83
8.2.1.2 Heuristic Evaluation ............................................................................ 90
8.2.1.3 Summary ............................................................................................... 92
8.2.2 Section 2: Between Groups ....................................................................... 94
8.2.2.1 Think-Aloud Protocol Evaluation ......................................................... 94
8.2.2.2 Heuristic Evaluation ............................................................................ 95
8.2.2.3 Summary ............................................................................................... 96
8.2.3 Section 3: Think-Aloud Protocol versus Heuristic Evaluations .................. 97
8.2.3.1 Sydney Opera House .......................................................................... 97
8.2.3.2 Questacon Science Center ................................................................. 98
8.2.3.3 Wroxton Abbey ................................................................................... 99
8.2.3.4 Richard Strauss House ........................................................................ 101
8.2.3.5 Summary ............................................................................................... 104

8.3 Chapter Summary ......................................................................................... 104

Chapter 9 Discussion ......................................................................................... 105
9.1 Section 1: Broad Themes Analysis Experimental Results ............................... 107
9.1.1 Functionality ............................................................................................. 107
9.1.2 Interactions ............................................................................................... 109
9.1.3 Appearance .............................................................................................. 112
9.1.4 User Comments ....................................................................................... 113
9.1.5 Summary ................................................................................................. 116

9.2 Section 2: Large-scale versus small-scale VE systems .................................... 117

9.3 Section 3: Broad themes and sub-themes versus Koykka et al. ...................... 117
9.3.1 3D environments should provide support for orientation, navigation and movement ................................................................. 118
9.3.2 Real world metaphors need to be clearly understandable ......................... 118
Table of Contents

9.3.3 Avoidance of delay and waiting periods in performance ........................................ 119
9.3.4 Summary for the Koykka et al. and experimental results ..................................... 119

9.4 Section 4: Evaluation and analysis methods ............................................................... 119
9.4.1 Heuristic evaluation ................................................................................................. 119
9.4.2 Think-aloud protocol ............................................................................................... 120
9.4.3 Emergent themes analysis (ETA) approach .............................................................. 120
9.4.4 Summary .................................................................................................................. 120

9.5 Section 5: Limitations and Future Research ............................................................... 121
9.5.1 Limitations .............................................................................................................. 121
9.5.1.1 Time constraints ................................................................................................. 121
9.5.1.2 Complexity of ETA ............................................................................................ 121
9.5.1.3 Experimental Methodology ............................................................................... 121
9.5.2 Future Research ..................................................................................................... 122
9.5.2.1 Alternative VE usability evaluation methods available ....................................... 122
9.5.2.2 Large- versus small-scale VE systems evaluation of other virtual environments ... 123
9.5.2.3 Quantitative analysis of the think-aloud protocol data ....................................... 123

9.6 Chapter Summary ...................................................................................................... 123

Chapter 10  Conclusions ................................................................................................. 125

References ....................................................................................................................... 127

Appendices ....................................................................................................................... 134

Appendix A: Virtual Environments .................................................................................. 135
A1. Sydney Opera House (Sydney, Australia) ................................................................. 136
A2. Questacon Science Center (Canberra, Australia) ...................................................... 137
A3. The Wroxton Abbey (Oxfordshire, England) ............................................................ 139
A4. Richard Strauss’ House (Garmisch, Bavaria) ............................................................ 141

Appendix B: Ethical Approval ......................................................................................... 142

Appendix C: TAP VE Task Sheets .................................................................................... 151

Appendix D: Data Collection Sheet .................................................................................. 164

Appendix E: TAP and Interview Questions ..................................................................... 166

Appendix F: Usability Heuristic Evaluation Equipment ................................................ 168

Appendix G and H: Emergent Themes Analysis of the Heuristic Evaluation and Think-Aloud Protocol Data CD .................................................. 170
Table of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2-1</td>
<td>A Classification of Virtual Reality Systems (adapted from Biocca and Delaney, 1995, p. 59)</td>
<td>7</td>
</tr>
<tr>
<td>Table 3-1</td>
<td>Strengths and weaknesses of Qualitative Research (Peterson, K. 2001)</td>
<td>22</td>
</tr>
<tr>
<td>Table 3-2</td>
<td>Choosing a statistical technique (Dix, A., Findlay, J. E. et al. 2004)</td>
<td>25</td>
</tr>
<tr>
<td>Table 4-1</td>
<td>Questions and factors addressed when choosing an evaluation method (modified from Wong, B.L. W., 2001)</td>
<td>31</td>
</tr>
<tr>
<td>Table 4-2</td>
<td>Nielsen’s heuristics and questions to be addressed in a system evaluation</td>
<td>36</td>
</tr>
<tr>
<td>Table 4-3</td>
<td>Five-point rating scale for the severity of usability problems found by heuristic evaluation (Nielsen, J. 1994)</td>
<td>36</td>
</tr>
<tr>
<td>Table 4-4</td>
<td>Ben Shneiderman and Donald Norman’s “Golden Rules and Heuristics” for producing usable systems (Dix, A., Findlay, J. E. et al. 2004)</td>
<td>38</td>
</tr>
<tr>
<td>Table 4-5</td>
<td>Usability Evaluation Methods Summary modified from (Axup, J. 2002)</td>
<td>42</td>
</tr>
<tr>
<td>Table 4-6</td>
<td>Limitations of traditional usability methods for assessing virtual environments (Stanney, K. M., Mollaghasemi, M. et al. 2003)</td>
<td>50</td>
</tr>
<tr>
<td>Table 5-1</td>
<td>Questionnaire design of Usability Factors and goals from VRUSE (Kalawsky, R. S. 1999)</td>
<td>52</td>
</tr>
<tr>
<td>Table 5-2</td>
<td>Nielsen’s Usability Heuristics (Nielsen, J. 1997)</td>
<td>60</td>
</tr>
<tr>
<td>Table 5-3</td>
<td>Sample results from evaluating a desktop photo-realistic virtual environment called Wroxton Abbey using Nielsen’s ten heuristics</td>
<td>60</td>
</tr>
<tr>
<td>Table 5-4</td>
<td>Five-point rating scale for the severity of usability problems found by heuristic evaluation (Nielsen, J. 1994)</td>
<td>61</td>
</tr>
<tr>
<td>Table 6-1</td>
<td>Web-based Photo-realistic VE systems evaluated in this research</td>
<td>69</td>
</tr>
<tr>
<td>Table 6-2</td>
<td>Nielsen’s (1994) Usability Heuristics</td>
<td>76</td>
</tr>
<tr>
<td>Table 6-3</td>
<td>Deriving a broad theme</td>
<td>81</td>
</tr>
<tr>
<td>Table 6-4</td>
<td>Broad Themes identified from the Think-Aloud Protocol between the Sydney Opera House versus the Questacon Science Center and the Wroxton Abbey versus the Richard Strauss House</td>
<td>83</td>
</tr>
<tr>
<td>Table 6-5</td>
<td>Broad Themes identified from the Heuristic Evaluation of the Sydney Opera House versus the Questacon Science Center and the Wroxton Abbey versus the Richard Strauss House</td>
<td>90</td>
</tr>
<tr>
<td>Table 6-6</td>
<td>Broad Themes found from the Think-Aloud Protocol of Large VE Systems (Sydney Opera House and the Questacon Science Center) versus Small VE Systems (Wroxton Abbey and the Richard Strauss’ House)</td>
<td>94</td>
</tr>
<tr>
<td>Table 6-7</td>
<td>Broad Themes found from the Heuristic Evaluation of Large VE Systems (Sydney Opera House and the Questacon Science Center) versus Small VE Systems (Wroxton Abbey and the Richard Strauss’ House)</td>
<td>95</td>
</tr>
<tr>
<td>Table 6-8</td>
<td>Think-Aloud Protocol versus Heuristic Evaluation for Sydney Opera House..</td>
<td>97</td>
</tr>
<tr>
<td>Table 6-9</td>
<td>Think-Aloud Protocol versus Heuristic Evaluation for Questacon Science Center.</td>
<td>98</td>
</tr>
<tr>
<td>Table 6-10</td>
<td>Think-Aloud Protocol versus Heuristic Evaluation for Wroxton Abbey</td>
<td>99</td>
</tr>
<tr>
<td>Table 6-11</td>
<td>Think-Aloud Protocol versus Heuristic Evaluation for Richard Strauss House</td>
<td>101</td>
</tr>
<tr>
<td>Table 6-12</td>
<td>Think-Aloud Protocol versus the Heuristic Evaluation across all systems</td>
<td>103</td>
</tr>
</tbody>
</table>
Table 9-1. Relationship between the Functionality sub-broad themes and Nielsen’s usability heuristics ................................. 109
Table of Figures

Figure 2-1. Simplified representation of a 'degree of immersion continuum' from Table 2-1 Classification of Virtual Reality Systems (adapted from Milgram and Kishino's Mixed Reality Taxonomy, 1994) ................................................................. 8

Figure 2-2. An example of a VRML walkthrough of a building (Beekman, G. 2001) ....... 9

Figure 2-3. An example of a QTVR Panorama Movie. Italy's Leaning Tower of Pisa from the Virtual Reality of Italy collection “to promote the free flow of ideas” as part of the United Nations Educational Scientific and Cultural Organization (UNESCO) Motto (CompArt Multimedia 1995-2003) ................................................................. 11

Figure 2-4. An example of a QTVR Object Movie. Virtual Joint used at the Wright State University's School of Medicine, U.S.A (Nieder, G. L. and Peirce, P. L. 1998). The VR allows medical students to view rotate, bend and learn about the movements and functions of a human the joint by dragging the mouse and clicking on specific areas of the joint ................................................................. 11

Figure 2-5. A desktop panoramic VR system of Harvard University. It shows the user different areas of the campus such as historical buildings and navigational instructions as how to get from one place to another ........................................... 13

Figure 2-6. A desktop panoramic VR system of the Sydney Opera House in Sydney Australia. It allows the user to see, move and read information about the different areas of the opera house ................................................................. 13

Figure 2-7. An example of a desktop VRML VR application for determining commodity prices called Investor Space from Maxus Systems (Maxus Systems International 2001) ................................................................. 14

Figure 2-8. An example of a CAVE VR system application used by European Car Manufacturer, Peugeot, in evaluating the design interior of a pre-production car. (Autoweb.com.au 2002) ........................................................................ 14

Figure 2-9. Amputee performing the pegboard exercise with sleeve designed for healthy subjects using desktop VR (Kuttuva, M., Flint, J. A. et al. 2003) ............... 15

Figure 2-10. Laparoscopic surgery, using an augmented reality telepresence VR system, which shows how to simulate minimally-invasive surgery (Larsson, S. 2003). 15

Figure 2-11. An immersive VR system displaying the tiny structures of the inner ear using a system called ImmersaDesk. (VRMedLab 2000) ................................................................. 15

Figure 2-12. A vehicle-based VR system such as a Visual Motion Simulator is used by US NASA to train astronauts in before space missions ......................... 16

Figure 2-13. Evans and Sutherland Mission Command Training for mission planning and mission rehearsal is another example of a vehicle-based VR system. In this case, it is used in a flight simulator (Evans & Sutherland - Visual Systems Solutions for Army Simulation and Training 2003) ................................................................. 16

Figure 2-14. University of Otago's School of Dentistry using a desktop photo-realistic, object VR to learn how to perform a tooth amalgam (Clark, S. A., Wong, B. L. W. et al. 2000) ........................................................................ 17

Figure 2-15. Dunedin's Macandrew Bay Intermediate Year Six students interpretation of the Dunedin Peninsula (Peterson, K. 2001) ................................................................. 17

Figure 2-16. A screenshot of DOOM 3D game using a desktop VRML: VR system ...... 17

Figure 2-17. Another example of a desktop VRML multi-user 3D game called Uru: Ages Beyond Myst ................................................................. 17
Figure 2-18. A desktop object VR system showing a 360° view of Sony Ericsson P800 Mobile Phone. The VR allows you to zoom in and out, rotate the phone, move it left to right, up and down................................................................. 18

Figure 2-19. A desktop panoramic VR system showing how Domaine Homes Real Estate, Australia is using photo-realistic VR to market a client’s home ........................................... 18

Figure 4-1. Curve showing the proportion of usability problems in an interface found by heuristic evaluation using various numbers of evaluators. The curve represents the average of six case studies of heuristic evaluation (Nielsen, J. 1994; Preece, J., Rogers, Y. et al. 2002) ...................................................... 37

Figure 5-1. A five-point Likert attitude scale used in VRUSE (Kalawsky, R. S. 1999) .... 52

Figure 6-1. Individual Heuristic Evaluation Results aggregated into Group results from a desktop, photo-realistic virtual environment .............................................. 61

Figure 6-2. CDM Decision Analysis Process – Incident Summaries are broken down to a timeline in a decision chart. Cues, goals, mental processing and other interesting aspects are categorized across incidents .................................................. 64

Figure 6-3. Data is further reduced by summarizing themes according to categories ...... 64

Figure 6-4. Emergent Themes Analysis process ...................................................... 65

Figure 7-1. Between and within subject experimental design. Large and small VE systems will be compared within and between their respective categories .......... 69

Figure 7-2. Starting node of VE System 1 - the Sydney Opera House ...................... 70

Figure 7-3. Starting node of VE System 2- the Questacon Science Center ............... 70

Figure 7-4. Starting node of VE System 3 – the Wroxton Abbey............................ 70

Figure 7-5. Starting node of VE system 3 - the Richard Strauss House .................... 70

Figure 7-6. The two digital video recorder cameras used to collect the user’s keystrokes, screen mouse movements and speech as they used the desktop VE system..... 72

Figure 7-7. Some examples of participants conducting a think-aloud protocol evaluation. The participant on the left was exploring the VE system. While the participant on the right was reading the tasks sheet............................. 75

Figure 7-8. An electronic Microsoft 2000 Excel file example that the evaluators used to record their individual usability heuristic evaluation................................. 76

Figure A1-I. The start-node of the Sydney Opera House ........................................ 136

Figure A2-I. This is the start page of the Questacon Science Center. At the start of the tour, there are some note tips that the user reads and then closes to provide them with some information as how to navigate their way around .......................... 137

Figure A2-2. This is an inside view of one of the locations within the Questacon Science Center called the Drum Ramp............................................................... 138

Figure A3-I. The start node of the Wroxton Abbey................................................. 139

Figure A3-2. This is one of the inside panorama VR within Wroxton Abbey. This is the view from the Entrance Hallway ......................................................... 140

Figure A4-I. This is the Façade. The outside area of the house ............................... 141
## Table of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>3D</td>
<td>Three-dimensional</td>
</tr>
<tr>
<td>ETA</td>
<td>Emergent Themes Analysis</td>
</tr>
<tr>
<td>HE</td>
<td>Heuristic Evaluation</td>
</tr>
<tr>
<td>HMDs</td>
<td>Head Mounted Displays</td>
</tr>
<tr>
<td>QTVR</td>
<td>QuickTime Virtual Reality</td>
</tr>
<tr>
<td>QTVRAS</td>
<td>QuickTime Virtual Reality Authoring Studio</td>
</tr>
<tr>
<td>TAP</td>
<td>Think-Aloud Protocol</td>
</tr>
<tr>
<td>VE</td>
<td>Virtual Environment</td>
</tr>
<tr>
<td>VEs</td>
<td>Virtual Environments</td>
</tr>
<tr>
<td>VR</td>
<td>Virtual Reality</td>
</tr>
<tr>
<td>VRML</td>
<td>Virtual Reality Modelling Language</td>
</tr>
</tbody>
</table>
Chapter 1  Introduction

1.1 Background and Research Objectives and Aims

The use of virtual reality (VR) systems, a three-dimensional, computer-generated environment, has become more prominent over the last decade. There has been an increase of both computer generated image systems using tools like Virtual Reality Modelling Language (VRML) as well as photo-realistic image tools like Apple's QuickTime Virtual Reality Authoring Studio (QTVRAS), Internet Pictures Corporation's iPIX and Helmut Dersch's PanoTools. With proliferated use of such systems in diverse fields of medicine, entertainment, tourism and marketing, it has been quite difficult to determine whether what is being made is actually usable in terms of a system's memorability, ease of use, ease of learning, robustness and user satisfaction. There has been very limited research done in terms of evaluating the usability of VR systems, particularly those of a desktop, photo-realistic nature. This study has three purposes:

- First, to determine whether applying the same usability evaluation methodologies of think-aloud protocol, interviews and heuristic evaluation tested by Koykka, Ollikainen, Ranta-aho, Milszus, Wasserroth and Friedrich (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would also produce additional usability guideline categories.

- Second, to determine whether think-aloud protocol or usability heuristic evaluation is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environment.
• Third, to determine whether large-scale desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments.

It is hoped that by investigating these aims that design guidelines for desktop, photo-realistic, virtual environment may be derived.

These aims will be addressed in the following manner as overviewed in the structure of this thesis.

1.2 Structure of the Thesis

The remainder of the thesis is structured as follows:

Chapter 2 Virtual Reality Technology
A literature review regarding virtual reality technology is presented in Chapter 2. The first section defines "virtual reality", providing a brief history of VR and a classification list of VR systems. This is followed by a discussion on immersion and presence, considered to be a key characteristic of all VR systems. As the focus of this thesis is on desktop VR, a non-immersive system, two of the most widely used desktop approaches are described. The second section provides examples of VR applications in visualization, medicine, training, education, recreation and entertainment, and sales and marketing sectors.

Chapter 3 Qualitative Research Methods
Chapter 3 presents a discussion of the various research methods that are relevant to the study's objectives with emphasis on qualitative research methods like grounded theory, action research, case study and ethnography. In addition, quantitative methods such as surveys and lab experiments will be briefly discussed. Greater emphasis will be placed on the qualitative research methods as one of the purposes of the study is to compare the suitability of two qualitative techniques, namely, think-aloud protocol and usability heuristic evaluation in determining if similar results are found like that in the Koykka et al. (1999) study when applied in a photo-realistic virtual environment.

Chapter 4 General Usability Evaluations
A literature review regarding usability and usability evaluations is presented in Chapter 4. The first section defines usability and the importance of applying usability evaluations. The second section discusses the different evaluation methods and techniques. As the focus of this thesis is on the comparative study of heuristic evaluation and think-aloud protocol, each of qualitative approach is described in greater detail.
Chapter 5 Usability evaluation of virtual environments

Chapter 5 presents a literature review of usability evaluations of virtual environments particularly of VE interactions such as navigation, selection and searching and heuristic evaluations of photo-realistic desktop VRs will be discussed in greater detail. The first section describes different characteristics that make a virtual environment usable with particular emphasis on interaction mechanisms. The second section briefly presents usability findings from reviewed virtual environments usability evaluations. The final section describes the focus of this study.

Chapter 6 Research Techniques

Chapter 6 presents the qualitative techniques used in this study. A think-aloud protocol and heuristic evaluation will be used to elicit narrative data from the participants, which are then presented and discussed. An Emergent-Themes Analysis (ETA) approach, which is an iterative distillation process developed by Wong and Blandford (2002) will be used to analyze the narrative data.

Chapter 7 Experimental Methodology

Chapter 7 will describe the experimental resources and procedures used and performed in this study. A think-aloud protocol, interview and Jakob Nielsen’s heuristic evaluation was used in this study to compare four web-based, non-immersive, desktop, photo-realistic virtual environments. Two are large-scale and two are small-scale.

Chapter 8 Experimental Results

Chapter 8 will present the results of the think-aloud protocol, interviews and heuristic evaluation of four web-based desktop photo-realistic virtual environments evaluated in this study. The Emergent-Themes Analysis (ETA) approach by Wong and Blandford (2002) will be used to analyze the data. The results are divided into three sections: (1) a within group analysis of similar scale VEs, (2) a between group analysis of large- and small-scale VEs and (3) a comparison of the think-aloud protocol and heuristic evaluation within each desktop, web-based, photo-realistic VE will be presented.

Chapter 9 Experimental Results Discussions and Future Research

Chapter 9 will reflect upon the results of the study by providing a review of significant findings, together with interpretations, implications and any related factors that merit discussion. Functionality, interaction, appearance, user comments are the four broad themes identified from the ETA analysis. Broad theme results will be compared with results found in the Koykka et al., 1999 study. Furthermore, results from comparing large- versus small-scale VE systems will also be discussed as well as the limitations of the current research methods used. Limitations and future research with regards to the current study will also be discussed.
Chapter 10 Conclusions
Chapter 10 will present the conclusions found in this study and possible future directions.

1.3 Chapter Summary

This study is about evaluating non-immersive desktop photo-realistic virtual environments using think-aloud protocol and heuristic evaluation similar to a study conducted by Koykka, et al. in 1999. There are three hypotheses in this study as stated in the start of this chapter. They are:

- First, applying the same usability evaluation methodologies of think-aloud protocol, interviews and heuristic evaluation tested by Koykka, Ollikainen, Ranta-aho, Milszus, Wasserroth and Friedrich (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would produce additional usability guideline categories.

- Second, think-aloud protocol analysis is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environment than a heuristic evaluation (established by Emergent Themes Analysis).

- Third, large-scale non-immersive, desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments because of the complexity of large-scale systems.
Chapter 2 Virtual Reality Technology

2.1 Introduction

Throughout the years, the term virtual reality (VR) connotes an image of users “freely” interacting with a computer-generated world as if it is real. This section will describe origins of virtual reality, its different classifications and applications.

2.1.1 Overview of Virtual Reality

The development of the technology which eventually led to virtual reality was rather slow. The history spans for more than seven decades and in certain aspects of engagement, immersion and presence preceded the advent of the computer (Chorafas, D. N. and Steinman, H. 1995). Even now, virtual reality is still far from a true representation of the real world. Interaction requires obtrusive equipment such as Head-Mounted Display (HMDs) and costly software to experience a seamless, computer-generated “reality” (Heim, M. 1993).

Throughout the past seventy years, various sources of inspirations ranging from the field of engineering, aviation, mathematics, physics, arts and science have significantly contributed to the development of the technology known as virtual reality. Pioneers like Edwin Link’s Flight Simulator, Ivan Sutherland’s HMD, Myron Kruger’s Video Place and Force Feedback machines developed by Frederick Brooks Jr (Brooks Jr, F. P. 1999; Eddings, J. 1994; Krueger, M. W., Gionfriddp, T. et al. 1985; Link Jr, E. A. 2002; SunMicrosystems 1999) have all influenced the development of virtual reality. Today, researchers are still fascinated with replicating the real world using computers, aiming to create that one, true and virtual reality.
2.1.2 Virtual Reality, Virtual Environments, Virtual Worlds, Cyberspace

Virtual Reality (VR), Virtual Environments (VE), Virtual Worlds (VW), and Cyberspace are all valid terms for attempts attempting to replicate the real world using computers. Various literatures offer the following definitions to the terms above.

Virtual Reality (VR) - (first coined by Jaron Lanier during the mid 80s) refers to the use of specific resources of computer technology to provide its users with a three-dimensional computer-based environment. It is usually modelled from the real world in such a way that the computer channels information into the user’s senses leading the user to believe and feel that he is immersed in the environment (J. Monnet, 1995 cited in (Boza, W. 2002); (Eddings, J. 1994; Vince, J. 1998)).

Virtual Environments (VE) – refers to an interactive, immersive, multi-sensory three-dimensional, computer-generated environment provided by a virtual environment system. It is a human-computer interface that provides a “perfect” (intuitive, perceivable and an experience-able) simulation of the real world environment in a synthetic world. (Bullinger, H. J. 1997; Stuart, R. 2001). Furthermore, Zeltzer (1992) describes virtual environments in terms of autonomy (environment and object behaviour - action and reaction of the model through user interaction), interaction (the ability to define and modify states of a model with different immediate response) and presence (the engagement of our sensory cues allowing the user to attain a ‘sense of being in and of the world’.) (Zeltzer, D. 1992)

Virtual Worlds (VW) - enable users to enter the make believe world and experience it as it is real (rather than just observing “reality”) (Chorafas, D. N. and Steinman, H. 1995). It is constructed by the senses and only really exists in the mind of the users (Biocca, F. and Delaney, B. 1995).

Cyberspace - refers to a “metamedium” that gives the user the feeling of being transported from the real world into a more abstract and imagined world generated by a computer. It allows movement within this computer-generated world the way people move around a physical setting providing the sensation of being there (Chorafas, D. N. and Steinman, H. 1995).

Virtual reality is a combination of the all the definitions above and can be defined as a three-dimensional, computer-generated environment that allow for a single or multiple users to interact, navigate, respond, and experience a synthesized world modelled from the real world in an intuitive manner where the sense of presence can be delivered in an immersive or non-immersive system.

2.2 Virtual Reality Technology

The last thirty-nine years has seen vast development in VR technology since Sutherland’s first HMD in 1965. It is the development and advancement in hardware like the Kaidan Pano Head, and Apple’s QuickTime Virtual Reality Authoring Studio (QTVRAS) stitching software for producing desktop, photo-realistic virtual environment, that has continually contributed to more affordable and hence, accessible methods of creating and viewing VR systems. Table 2-1 (below) suggests a classification and relevant examples of virtual reality systems.
Chapter 2: Virtual Reality Technology

Table 2-1. A Classification of Virtual Reality Systems (adapted from Biocca and Delaney, 1995, p. 59)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersive virtual reality systems</td>
<td>Users wear displays that fully immerse a number of the senses in computer-generated stimuli. The stereoscopic head-mounted displays (HMD) are a distinctive feature of such systems.</td>
<td>The Virtual Reality Responsive Workbench (Navy, U.S. 2003)</td>
</tr>
<tr>
<td>Cave Automatic Virtual Environment (Cave) systems</td>
<td>Users enter a room or enclosure where they are surrounded by large screens that project a nearly continuous virtual scene. 3D glasses are sometimes used to enhance the sense of space.</td>
<td>The CAVE Virtual Reality System (Cruz-Neira, C., Sandin, D. et al. 2001)</td>
</tr>
<tr>
<td>Vehicle-based systems</td>
<td>The users enter what appears to be a vehicle (e.g., tank, plane, car, space ship, etc) and operate controls that stimulate movement in the virtual world. The world is most often projected on screens. The vehicles may include motion platforms to simulate physical environment.</td>
<td>British Airways747 simulator, Warsash Merchant ship simulation, NASA Astronaut training (Brooks Jr, F. P. 1999)</td>
</tr>
<tr>
<td>Augmented reality systems (Tele-presence and Tele-operations)</td>
<td>Similar to immersive VR systems where the users wear a visual display (e.g. transmissive HMD) that superimposes 3-D virtual objects on real world scenes.</td>
<td>Wearable computers (Ciufò, C. 2000)</td>
</tr>
<tr>
<td>Mirror systems</td>
<td>The users look at the projection screen and see an image of themselves moving in a virtual world. Video equipment is used to record the user’s body. A computer superimposes a cutout image on a computer graphic background. The cutout images of themselves on the screen mirrors their movements, hence the name, <strong>mirror systems</strong>.</td>
<td>Smart Rooms at MIT (Pentland, A. 1996)</td>
</tr>
<tr>
<td>Desktop system</td>
<td>A computer screen provides a window or portal onto an interactive, 3-D virtual world. Desktop computers are often used and users sometimes wear 3D glasses for stereoscopic effects.</td>
<td>Apple's QuickTime Virtual Reality (Chen, S. E. 1995); A.D.A.M. (Velgos, T. 1998); Tourism (Cooper, M. and Benjamin, I. 1995; Villanueva, R. and Wong, B. L. W. 2001)</td>
</tr>
</tbody>
</table>

2.2.1 Immersive versus Non-Immersive Virtual Reality Systems

Table 2-1 classifies VR systems according to their immersion levels. Immersion is one of the key characteristics of a VR system, resulting in a feeling of presence. It is important to understand the difference between immersion and presence and, hence, is briefly defined below.

Presence is referred to as the engagement of senses through strong perceptual illusion. It immediately suggests that the user will have sensations being present in an environment and will perceive objects found there as equally present (Biocca, F. and Delaney, B. 1995).

The level of immersion determines the user’s impression of presence within a virtual environment. It is also the type and quality of impressions that determines the level of immersion. The more the system captivates the senses and blocks out stimuli from the physical world, the more the system is considered to be immersive (Boza, W. 2002; Bullinger, H. J. 1997; Chorafas, D. N. and Steinman, H. 1995; Eddings, J. 1994; Stuart, R. 2001).

Figure 2-1 presents a ‘degree of immersion continuum’ of the different types of Virtual Reality Systems based on Table 2-1. This figure was adapted from Milgram and Kishino’s Mixed Reality Taxonomy (Milgram, P. and Kishino, F. 1994).
Chapter 2: Virtual Reality Technology

Among the classifications, only Desktop VR system is considered to be a non-immersive system. Many researchers believe that full body immersion is a key definition of VR and doubt whether Desktop VR is an example of a VR system (Wilson, J. R. 1999).

An important distinction between an immersive and non-immersive VR system has been developed as a result of the Internet (Xiao, D. Y. 2000). Immersive VR uses simulators, data gloves, body suits and stereoscopic displays like HMDs, which block out the surrounding world and present stimuli to the user in response to position and orientation of the user's head (Stuart, R. 2001). However, immersive VR is far from ideal as there are still issues associated with HMD VR techniques such as poor display resolution, display jitter, lag between head movement and the resulting change to the display, that tend to inhibit the illusion of immersion and clearly not a problem in desktop VR system.

Desktop VR is considered to be non-immersive and relies on standard desktop monitors to view the environment from a certain vantage point with a keyboard and mouse to interact with objects within the desktop environment. This approach provides a more realistically feasible alternative due to its hardware and software being much more affordable compared to that of some immersive VR systems.

Regardless of the advantages above, the focus of the media and many research programs has been on the immersive forms of VR (Monnet, B. 1995). This is slowly changing as non-immersive desktop VR systems are less expensive and therefore opens the new technology to a much wider user base and are now an important market sector (Goetze, E. 2002; Monnet, B. 1995).

The following section describes the two most widely used desktop approaches: Virtual Reality Modeling Language (VRML) and QuickTime Virtual Reality (QTVR).

### 2.2.1.1 Non-Immersive Desktop VR – Virtual Reality Modeling Language (VRML)

The Virtual Reality Modeling Language (VRML) is a model-based format. It is a format for describing three-dimensional interactive worlds and objects that can be used together with the World Wide Web (WWW)/Internet as the interface (Dix, A., Finlay, J. et al. 1998;
Steinmetz, R. and Nahrstedt, K. 2002). In 1994, the growth of the Internet has led to the development of an interconnected and platform-independent standard for 3D WWW applications. During this time, VRML 1.0 was created and developed by members of the VRML Architecture Group (VAG), a party consisting of eight technical experts endeavouring to focus and articulate the sentiments of the VRML community to foster the development of a scalable, fully interactive standard for cyberspace (VAG 1999). This text-based language allowed creation of 3-D objects with embedded hyperlinks to be incorporated in scenes. It also allowed users to move around the virtual environment.

In 1997, VRML 2.0 was presented, which featured added support for interactivity using scripts, such as the ability to embed the use of audio and video in the VRML world. It is also important to note that VRML 1.0 and 2.0 were for single user systems. As the popularity of the Internet continued to rise, the VRML Consortium, which were responsible for developing VRML further, recognized that there was a need to develop a fully robust, multi-user system as well as consistent standards for avatars and ‘robots’ representation and programming (Howard, T. 1997). Thus, became the goal in the current development of VRML 3.0. Figure 2-2 is an example of a VRML walkthrough of a building, containing objects with links that can be activated resulting movement to another web page or VRML location (Beekman, G. 2001).

Figure 2-2. An example of a VRML walkthrough of a building (Beekman, G. 2001).

The next section discusses another system used to create and present a desktop VR, which is different from VRML. Apple QuickTime Virtual Reality Authoring Software (QTVRAS) delivers a photo-realistic VR experience.
QuickTime Virtual Reality (QTVR) is a commercial product, developed by Apple Computers as part of the QuickTime digital multimedia framework (Chen, S. E. 1995). It is a virtual reality system that uses photo-realistic images taken from the real world using digital cameras or standard film, where photographs from film cameras are later scanned. It allows the exploration and examination of photo-realistic, three-dimensional virtual places and objects using a standard keyboard and mouse. Virtual places are shown using a panoramic movie (sometimes called panoramas), while objects are displayed using object movies. Panoramas usually have the user standing at the center of the panoramic movie and from this vantage point, the viewer can look anywhere within that panorama (Chen, S. E. 1995; Kitchens, S. A. 1998). Panoramas are used to show walkthroughs of places such as the inside of buildings and houses, parks, streets and its surrounding areas. On the other hand, object movies typically show objects that can be “handled” by tilting and rotating the object, enabling the user to see it from different angles (Chapman, N. and Chapman, J. 2000; Chen, S. E. 1995). Examples of object movie applications include educational and medical models, handling of artifacts like sculptures and museum pieces and marketing of products. Figure 2-3 and Figure 2-4 show examples of panoramic and object movies. QTVRAS is composed of two main environments: the authoring environment and the interactive environment, both are briefly discussed in the next sections.
Chapter 2: Virtual Reality Technology

Figure 2-3. An example of a QTVR Panorama Movie. Italy’s Leaning Tower of Pisa from the Virtual Reality of Italy collection “to promote the free flow of ideas” as part of the United Nations Educational Scientific and Cultural Organization (UNESCO) Motto (CompArt Multimedia 1995-2003)

Figure 2-4. An example of a QTVR Object Movie. Virtual Joint used at the Wright State University's School of Medicine, U.S.A (Nieder, G. L. and Peirce, P. L. 1998). The VR allows medical students to view rotate, bend and learn about the movements and functions of a human the joint by dragging the mouse and clicking on specific areas of the joint.

The Authoring Environment

QTVR primarily uses a cylindrical environment, although spherical and cubic environments can also be created, for spatial navigation using camera rotation. This environment consists of the authoring tools necessary to create the two types of VR movies: a panorama movie and an object movie.

A panorama movie has the user located in the center of the panoramic environment (also known as a node). It is also the center of the camera rotation, the degree of which ranges from 0°-360° (Chen, S. E. 1995; Kitchens, S. A. 1998). A single node panorama movie allows a user to look in all directions from that node. To obtain this view, individual images are collected using standard still or digital camera. The collected images are “stitched” with overlapping images to create a seamless panoramic view.

Contrary to a panoramic movie, an object movie, allows the user to interact with an object. The process of creating an object is opposite to a panoramic movie, where the camera is stationary. An object movie requires taking pictures from multiple perspectives, where the object is in the center of a sphere (Kitchens, S. A. 1998). Thus, the camera points and orbits around the object’s center at constant increments (Chen, S. E. 1995). Objects are typically placed on a rotating pedestal or turntable and are later removed using a graphic editor before the images are assembled into an object movie.
Both object and panorama movies can be combined to form a scene (a collection of several panoramas), an object within a panorama, or several panoramas and objects all linked together by an interactive hotspot. Hotspots are regions in an image that allow for interaction such as activating events or navigation (Chen, S. E. 1995). Panorama and object movies can be viewed using Apple QuickTime Player, which is briefly discussed in the next section.

The Interactive Environment

The interactive environment consists of the panorama player and the object player called Apple QuickTime Player. The panorama player allows the user to look around a space from the inside (being at the center of the panorama) outwards. The user has the ability to pan, zoom and navigate in a scene, achieved by dragging the mouse inside the panoramic environment. To move to another panoramic node, the user clicks on the hotspot, the pre-defined region for interaction.

The object player gives the user the ability to view the object from the outside looking towards the object (inwards). The object can use the mouse to rotate and tilt the object (using both x and y axes), allowing the user to view from several different viewing directions (Chen, 1995).

The above section has provided an overview of VR, a discussion of the types of VR and the importance of desktop VR systems. The following section examines the wide variety of VR applications.

2.3 Applications of VR

Throughout the last seven decades, the use of virtual environments for various purposes has increased (Brooks Jr, F. P. 1999; Bullinger, H. J. 1997). According to Boza (2002), it is the ability of VR technology, through immersion and interactivity, to enhance an experience, provide more possibilities in the designing and creating process, or to allow human presence in dangerous or impossible situations achievable in the VR environments, that has led to its use and development in the following diverse fields over the years.

2.3.1 Travel and Cultural Heritage

The use of desktop VR in the area of travel and cultural heritage is growing especially with greater access to the Internet and the faster data transfer rates. Travel services like providing a photo-realistic VR of a particular destination often adds value that may entice and influence customers in purchasing online holidays to white, sandy beaches of Fiji.

Furthermore, providing an on-line site tour with easily accessible information about locations of interest and significance before a person physically visits a site (for example, their child's colleges, local museums, historical landmarks) provide visitors a more informative and more
enjoyable visit. Figure 2-5 and 2-6 shows some examples of desktop, photo-realistic VRs of travel and cultural heritage applications.

This study will focus on this application type of non-immersive, desktop, web-based photo-realistic virtual environments.

Figure 2-5. A desktop panoramic VR system of Harvard University. It shows the user different areas of the campus such as historical buildings and navigational instructions as how to get from one place to another (HarvardOfficeofNewsandPublicAffairsandQuantumVRInternational 2000).

Figure 2-6. A desktop panoramic VR system of the Sydney Opera House in Sydney Australia. It allows the user to see, move and read information about the different areas of the Opera House (SydneyOperaHouse 2003).

2.3.2 Visualization Applications

Virtual reality aids in the visualization of complex data such as those from the financial markets (to represent the prices of various commodities) or geographic data. Examples of these desktop tools include Investor Space from Maxus Systems International for financial data representation (shown in Figure 2-7) (Eddings, J. 1994; MacDonald, L. and Vince, J. 1994; Warwick, K., Gray, J. et al. 1993; Wexelblat, A. 1993) and VRML for geographic data (Moore, K. 1999).

VR also allows the user to test design feasibility of objects like building structures (via walkthroughs), submarine design, aircrafts (virtual cockpit), automobiles (Brooks Jr, F. P. 1999; Bullinger, H. J. 1997; Stuart, R. 2001; Warwick, K., Gray, J. et al. 1993). It also assists in developing understanding of complex concepts from behavior of molecules (Brooks Jr, F. P. 1999; MacDonald, L. and Vince, J. 1994), to the workings of the human body.
Using VR for visualization purposes allows designers (and their clients) to determine patterns (financial), confirm prototype designs before building (lowers production costs) and understand molecular and chemical behaviors before attempting to replicate them in the real world. Figure 2-7 and 2-8 show examples of VR application for visualization purposes.

![Figure 2-7](image1.jpg) ![Figure 2-8](image2.jpg)

**Figure 2-7.** An example of a desktop VRML VR application for determining commodity prices called Investor Space from Maxus Systems (MaxusSystemsInternational 2001)

**Figure 2-8.** An example of a CAVE VR system application used by European Car Manufacturer, Peugeot, in evaluating the design interior of a pre-production car. (Autoweb.com.au 2002)

### 2.3.3 Medical Applications

There have been many applications of VRs in the field of medicine (MacDonald, L. and Vince, J. 1994). Patient treatment and medical training are some examples of a medical VR application.

Patient treatment for physical rehabilitation such as aiding the handicapped in re-developing motor skills using sound-oriented desktop for the blind; glove and gesture recognition or speech re-learning for people with aphasia (Travis, D., Watson, T. et al. 1994; Warwick, K., Gray, J. et al. 1993). VR is also used to treat people with psychological-related disorders such as anxiety and phobias to overcome a patient’s limitations (Brooks Jr, F. P. 1999; Bullinger, H. J. 1997; MacDonald, L. and Vince, J. 1994; Stuart, R. 2001; Wexelblat, A. 1993).

Furthermore, VR is also widely used in medical training and procedures such as in the study of the human body (virtual cadavers) for training surgeons (Velgos, T. 1998) or performing complicated surgery over wide distances (World's first interactive operation in hospital carpark 2003). Figure 2-9, 2-10 and 2-11 show some examples of medical applications of VR systems.
2.3.4 Training Applications

The use of VR for job-oriented training, in the form of simulation, allows trainees to practice tasks that will later be performed in the real world. The virtual environment provides a “close enough” scenario to allow trainees to psychologically and sometimes physically prepare by experiencing “real” situations before they happen (Brooks Jr, F. P. 1999; Bullinger, H. J. 1997; Stuart, R. 2001). This is an advantage as research shows that VR simulations improve people’s natural abilities (Warwick, K., Gray, J. et al. 1993). Furthermore, real world training for some skills can be expensive, impractical or even dangerous. VR allows training without risking the trainees’ lives nor wasting real resources (Boza, W. 2002; Warwick, K., Gray, J. et al. 1993). VR training is also more cost-effective, portable, configurable and available. The experiences it provides through simulation are important in the training fields of aeronautics (real and offline training for space missions and aircraft flying) (Brooks Jr, F. P. 1999; Stuart, R. 2001), military applications such as SIMNET (Sohl, B. 2002) and police training. Figure 2-12 and 2-13 shows a vehicle-based VR system being used in motion training, command mission planning and scenario training.
2.3.5 Education

From an educational perspective (such as something that is learnt at school or at university level), the use of VR provides a learning experience that can actually be more exciting and enriching for students if they have an immersive and interactive contact with the subject of study e.g. University of Otago's School of Dentistry used QTVR to learn about different operative dentistry procedures (shown in Figure 2-14) (Evans & Sutherland - Visual Systems Solutions for Army Simulation and Training 2003). Educational training is different from the VR Training applications mentioned above as educational training is not as highly critical as it would be in a space or command control mission.

Another example of a VR application in an educational perspective is Dunedin's Macandrew Bay Intermediate School students learning about geography by using QTVR to model their immediate environment. In this case, the inlet of the Macandrew Bay is shown in Figure 2-15 (Clark, S. A., Wong, B. L. W. et al. 2000).

This application of work, is not only for very skilled levels, but also for lower levels where students could “travel” to the past or go to the rainforest using VR devices, making the learning experience more attractive (Peterson, K. 2001). Furthermore, by incorporating VR, across the curriculum level, the benefits to students not only increase technology literacy but also communication, cooperation and comprehension level (Boza, W. 2002; Branigan, C. 2002; Macpherson, C. and Keppell, M. 1998; Peterson, K. 2001)
2.3.6 Recreation and Entertainment

VR can also solely be used for the enjoyment of the user such as in desktop virtual reality games like DOOM and MYST (Peterson, K. 2001; Stuart, R. 2001). Within this environment, each participant is allowed to navigate, within a complete 360-degree circle, interact, and are “immersed” in the 3D graphics to simulate a battle in real time with other players using their desktop screens. Furthermore, using VR allows the user different perspectives, providing the feeling of ‘being inside’ the game, which could ‘enhance’ such experiences (Vince, J. 1998) like when watching sport events, concerts and plays. Figures 2-16 and 2-17 show examples of VR use in gaming entertainment.
2.3.7 Sales and Marketing Applications

The use of VR in the field of sales and marketing is steadily increasing, especially with the increased use of the Internet. Virtual reality like QTVR can be used to market products such as clothing and services by showing available facilities when planning for events or when selling real estate (*see-before-you buy*). All applications give the user the sense of "being there" (*Cyanworlds.inc* 2003). Figure 2-18 and 2-19 show examples of desktop VR used for product marketing and real estate selling.

![Figure 2-18. A desktop object VR system showing a 360° view of Sony Ericsson P800 Mobile Phone. The VR allows you to zoom in and out, rotate the phone, move it left to right, up and down (*Kitchens, S. A. 1998*).](image1)

![Figure 2-19. A desktop panoramic VR system showing how Domaine Homes Real Estate, Australia is using photo-realistic VR to market a client’s home (*SonyEricsson 2003*).](image2)

2.4 Chapter Summary

Virtual Reality (VR) is a family of technologies that enable users to interact, navigate, respond, and experience a three-dimensional, computer-generated environment using various interaction devices. VR systems can either be immersive or non-immersive. Desktop systems like QTVR, which is an image-based, non-immersive, desktop system, allow the users to experience the virtual environment without the complicated virtual environment software and expensive hardware such as HMDs. VR technology has been used in many applications: visualization of data, medical application, various training situations, education, entertainment, sales and marketing. It is perhaps these various uses of the technology, particularly, in the QTVR desktop environment that leads to the question: What makes the user-interfaces of desktop VRs usable?

Chapter 3 will discuss the different types of research methods.
Chapter 3: Qualitative Research Methods

3.1 Introduction

This chapter outlines the difference between qualitative and quantitative research methods for the purpose of evaluating desktop photo-realistic virtual environments. The chapter briefly discusses the different research methods within the qualitative arena that are relevant to determining whether heuristic evaluations or a think-aloud protocol evaluation is more effective in determining usability problems in desktop, photo-realistic virtual environments.

There are two main categories of research methods: qualitative and quantitative. Each one is described in the following sections.

3.2 Qualitative Research Methods

Qualitative research methods were originally developed in the human and social sciences to enable researchers to study and understand social and cultural phenomena (Creswell, J. W. 1994; Denzin, N., K. and Lincoln, Y. S. 2000; DomaineHomes 2003; Locke, L. F., Silverman, S. J. et al. 1998; Merriam, S. B. 2002; Myers, M. D. 1997; Thomas, M. R. 2003).

Denzin and Lincoln (1994, p2) defined qualitative research methods as:

...a multi-method in focus, involving an interpretive naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret phenomena in terms of the meanings that people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials such as case study, personal experience, interview, observational – that describe routine and problematic moments and meanings in people’s lives.
Qualitative researchers can be found in many disciplines and fields, using a variety of approaches, methods and techniques. Examples of qualitative methods include action research, case study, ethnography, grounded theory, narrative analysis, post-modern research and phenomenology (Creswell, J. W. 1994; Denzin, N., K. and Lincoln, Y. S. 2000; Jennings, G. 2001; Locke, L. F., Silverman, S. J. et al. 1998; Merriam, S. B. 2002; Myers, M. D. 1997; Trochim, W. M. K. 1999). Qualitative research methods are designed to help researchers understand people and the social and cultural contexts within which they live. Kaplan and Maxwell (1994) cited in (Trochim, W. M. K. 1999) argue that the goal of understanding a phenomenon from the point of view of the participants and its particular social and institutional context is largely lost when textual data are quantified. According to Myers (1997), action research, case study, ethnography and grounded theory are appropriate qualitative research methods for Information Science (IS) research. Each one is briefly described below.

### 3.2.1 Grounded Theory

Grounded theory is a qualitative research approach that was originally developed by Glaser and Strauss in the 1960s (Merriam, S. B. 2002; Myers, M. D. 1997; Trochim, W. M. K. 1999). The self-defined purpose of grounded theory is to develop theory or to explain some phenomenon of interest (Merriam, S. B. 2002; Travers, M. 2001) by using multiple stages of systematic data collection, analysis, refinement and interrelationship of categories of information (Creswell, J. W. 1994; Myers, M. D. 1997; Strauss, A. and Corbin, J. 1998; Trochim, W. M. K. 1999). The term 'grounded theory' was derived from the theory being grounded or rooted based on interviews and observations (Merriam, S. B. 2002; Strauss, A. and Corbin, J. 1998).

Grounded theory is a complex iterative process. The research begins with the raising of generative questions, which help to guide the research but are not intended to be either static or confining. As the researcher begins to gather data, core theoretical concept(s) are identified. Tentative linkages are developed between the theoretical core concepts and the data. This early phase of the research tends to be very open and can take months. Later on, the researcher is more engaged in verification and summary. The effort tends to evolve toward one core category that is central (Chazman, K. 2000; Merriam, S. B. 2002; Strauss, A. and Corbin, J. 1998; Trochim, W. M. K. 1999). As indicated from the above section, grounded theory doesn’t have a clearly distinguishable point for ending a study. Essentially, the project ends when the researcher decides to quit or when an extremely well considered explanation has been reached (Chazman, K. 2000). The two primary characteristics of this design are the constant comparison of data with emerging categories (Creswell, J. W. 1994; Trochim, W. M. 1999).
Grounded theory approaches are becoming increasingly common in the IS research literature because the method is extremely useful in developing context-based, process-oriented descriptions and explanations of the phenomenon (Creswell, J. W. 1994).

3.2.2 Action Research

Action research also sometimes known as Participatory Action Research is concerned to enlarge the stock of knowledge of the social science community compared to applied social science where the goal is to apply social scientific knowledge rather than add to the body of knowledge (Denzin, N., K. and Lincoln, Y. S. 2000; Myers, M. D. 1997). Action research is used in applied settings such as the classroom or a health care environment. This approach involves the practitioner as a researcher collaborating with students or work colleagues in order to bring about change, to develop new skills or to problem solve in a particular situation that directly arises from the setting. A distinguishing feature of this approach is its spiraling and cyclical nature typically involving stages such as planning, action, observation and reflection. An example of action research is the introduction of self-assessment criteria for student learners by the researcher. The research would investigate the effect of this innovation. Collaborative and/or reflective aspects of such a project may include a discussion with students about their input, perceptions and evaluation of the innovation (1997). Action research has been accepted as a valid research method in the applied fields such as organization development and education.

3.2.3 Case Study

Case study methodology involves an in-depth exploration of a single entity, a single instance or phenomenon (“the case”) bounded by time and activity (a program, event process, institution, or social group) or with a small number of subjects by using a variety of data collection procedures during a sustained period of time (Research and Thesis writing: Research models and methods 2001; Creswell, J. W. 1994; 2002; Resource, S. D. L. 2001). The approach also provides an explanation as to why it acts the way it does. A case study research is the most widely used qualitative method in information systems as it allows researchers to determine what, how and why different factors interacted to produce a unique occurrence (Research and Thesis writing: Research models and methods 2001; Myers, M. D. 1997). However, a limitation of the case study method is generalizations and principles identified in one case being applied to other cases, which may not necessarily be true (Stake, R. E. 2000; Thomas, M. R. 2003). Ethnography is a special type of case study (Thomas, M. R. 2003), which is described next.
3.2.4 Ethnography

As suggested from the previous section, ethnography is a special type of case study. The ethnographic approach to qualitative research comes largely from the field of social and cultural anthropology, where the emphasis is on studying an entire culture in a natural setting during a prolonged period of time (Thomas, M. R. 2003). The ethnographer "immerses himself in the life of people he studies" (Creswell, J. W. 1994; Myers, M. D. 1997), enabling the researcher to understand the structure and inner workings of the group in its social and cultural context through participant observations, field notes, interviews and taped conversations (Research and Thesis writing: Research models and methods 2001; Myers, M. D. 1997; 2001; Thomas, M. R. 2003). Originally, the idea of a culture was tied to the notion of ethnicity and geographic location (for example, the culture of the Mayans), but it has been broadened to include virtually any group or organization (Research and Thesis writing: Research models and methods 2001). That is, we can study the "culture" of a business or defined group (for example, a classroom, a social club, an automobile agency etc). Whereas most case studies are intended to reveal the individualistic attributes of a particular person, organization, or event, the more common purpose of ethnographies is to identify beliefs and customs shared by members of a social system. In effect, case studies typically emphasize features that make one person or organization different from the others, whereas ethnographies more often emphasize the commonalities that unify members of a group (Denzin, N., K. and Lincoln, Y. S. 2000; Thomas, M. R. 2003; Trochim, W. M. K. 1999).

Ethnography has now become more widely used in the study of information systems in organizations, from the study of the development of information systems, to the study of aspects of information technology management, to its application as a method to gain multiple perspectives that can be incorporated in system design. Hence, its growing use by designers, information systems professionals, computer scientist and engineers, just to name a few (Thomas, M. R. 2003).

3.2.5 Strengths and Weakness of Qualitative Research Techniques

The strengths and weaknesses of qualitative research are summarized in Table 3-1 taken from Peterson (2001).

<table>
<thead>
<tr>
<th>Strengths of Qualitative Research</th>
<th>Weaknesses of Qualitative Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth and detail</td>
<td>Small population</td>
</tr>
<tr>
<td>Openness – can generate new theories and recognize phenomena ignored by most/all previous researchers and literature</td>
<td>Less easily generalized as a result</td>
</tr>
<tr>
<td>Helps people see the world view of those studies and simulates their experience of the world</td>
<td>Difficult to aggregate data and make systematic comparisons</td>
</tr>
<tr>
<td>Attempts to avoid pre-judgments, as the goal is to try and capture what is happening without being judgmental. Present people in their own terms, to represent them from their perspectives so readers can see their views</td>
<td>Depends upon researcher's personal attributes and skills. Participation in setting can always change the social situation</td>
</tr>
</tbody>
</table>

22
3.2.6 Validity of Qualitative Research

Ensuring validity in qualitative research can be achieved using triangulation. Triangulation is combining of one or more research methods in the one study of the same phenomena or programs (Myers, M. D. 1997; Peterson, K. 2001). According to Peterson (2001), there are four basic kinds of triangulation:

1. Data triangulation involving the use of a variety of data sources in a study.
2. Investigator triangulation involving the use of several researchers.
3. Theory of triangulation involving the use of multiple perspectives to interpret a single set of data.
4. Methodological triangulation involving the use of multiple methods to study a single problem or program.

Using triangulation in qualitative research is a way of neutralizing the bias inherent in particular data sources, investigators and methods (Denzin, N., K. and Lincoln, Y. S. 2000).

3.2.7 Summary for Qualitative Research Methods

In this section, different methods of qualitative research methods that are of relevance to the Information Systems field have been described. Action research, case study, ethnography and grounded theory are some of the qualitative methods being used in this field.

In this study, a variation of grounded theory method developed Wong and Blandford (2002) called Emergent Themes Analysis (ETA) will be used to identify broad themes from heuristic evaluation and think-aloud protocol data collected from evaluating desktop photo-realistic virtual environments. ETA is an iterative distillation process of voluminous data that help extract design insights by identifying themes and decision strategies (For example, from real-time operational environments such as emergency ambulance dispatch). The ETA method will be described in greater detail in 6.2.3.

The next section will briefly define quantitative research methods.

3.3 Quantitative Research Methods


Quantitative research uses numbers and statistical methods. It tends to be based on numerical measurements of specific aspects of phenomena; it abstracts from particular instances to seek general description or to test causal hypotheses; it seeks measurements and analyses that are easily replicable by other researchers.
Examples of quantitative methods now well accepted in the social sciences include survey methods and laboratory experiments (Trochim, W. M. K. 1999). Each one is briefly defined below:

### 3.3.1 Survey Methods

Survey methods are “snapshots at a particular point in time” (Myers, M. D. 1997) from which relationship inferences are made using quantitative techniques. It allows extrapolations of conclusions, from one collection of data, about the state of affairs over a longer period of time (Cockburn, A. 2003). Surveys are quite simple to design. A researcher poses a series of questions to willing participants; summarizes their responses with percentages, frequency, count or more statistical indexes; and draws inferences about a particular population from the responses of the sample. According to Leedy (2001), there are three types of surveys typically employed: face-to-face interviews, telephone interview or written questionnaire. Each one is briefly described next.

#### 3.3.1.1 Face-to-face Interviews

Interviews can be both qualitative and quantitative. In a qualitative study, interviews are often open-ended, perhaps revolving around one or a few central issues and participants freely give their response. In a survey research, interviews are more structured. This means researchers ask a set of standard questions and nothing more. Sometimes, answers are already predetermined with options, where the participant chooses from one that has been provided. Face-to-face interviews have the distinct advantage of enabling the researcher to establish rapport with potential participants and therefore gain their cooperation; thus such interviews yield the highest response rates in survey research. Personal interviews also allow the researcher to clarify ambiguous answers and, when appropriate, seek follow-up information. However, such type of interviews are both time consuming and expensive to conduct.

#### 3.3.1.2 Telephone Interviews

Telephone interviews are less time consuming and less expensive. The researcher has ready access to virtually anyone on the planet who has a telephone. Although the response rate is not as high as the face-to-face interview (due to respondents not available, interested or annoyed at being bothered), it is considerably higher than the mailed questionnaire. The researcher cannot establish the same kind of rapport that is possible in a face-to-face situation. It is also possible that the sample will be biased to the extent that people without phones are part of the population about whom the researcher wants to draw inferences.
3.3.1.3 Questionnaires

Paper-pencil questionnaires can be sent to a large number of people, including those who live overseas or another part of the country. This may save the researcher travel expense plus postage is typically cheaper than long-distance phone calls. Respondents of questionnaires have the assurance that their responses will be anonymous and thus, may be more truthful than they would be in a personal interview or in a telephone call. However, questionnaires have certain disadvantages such as the low response rate (between 25-30% (Cockburn, A. 2003)) and the people who return them are not necessarily representative of the originally selected sample. Even when people are willing participants in a questionnaire study, their responses will reflect reading and writing skills, and perhaps, their misinterpretation of one or more questions. Usually questionnaires are made up of checklist options or rating scales like Likert's attitude scale.

3.3.2 Laboratory Experiments

Laboratory experiment is a form of quantitative research that is conducted in a controlled environment. This form of research typically identifies precise relationships between chosen variables with a view to make generalized statements (Cockburn, A. 2003).

The purpose of a quantitative study is to develop generalizations that contribute to theory and enable researchers to better predict and understand some phenomenon. As such, concepts, variables and hypotheses are chosen before the study begins, and remains fixed throughout (Cockburn, A. 2003). This means that an experimental design is "drawn" where participants, variables and methods are decided upon. In most cases, statistical measures for analysis are also decided depending on the type of data being collected (discrete versus continuous variables, parametric or non-parametric tests) and the questions that is being answered (Cockburn, A. 2003; Dix, A., Findlay, J. E. et al. 2004). Table 3-2 presents a table of statistical techniques that can be used depending on the type of independent and dependent variable. The researcher generally remains distant and independent from the participants and attempts to control for bias and objectivity in assessing a situation.

Table 3-2. Choosing a statistical technique (Dix, A., Findlay, J. E. et al. 2004).

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Statistical technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parametric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two valued</td>
<td>Normal</td>
<td>Student's t test on difference of means</td>
</tr>
<tr>
<td>Discrete</td>
<td>Normal</td>
<td>ANOVA (Analysis Of Variance)</td>
</tr>
<tr>
<td>Continuous</td>
<td>Normal</td>
<td>Linear (or non-linear) regression factor analysis</td>
</tr>
<tr>
<td><strong>Non-parametric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two valued</td>
<td>Continuous</td>
<td>Wilcoxon (or Mann-Whitney) rank-sum test</td>
</tr>
<tr>
<td>Discrete</td>
<td>Continuous</td>
<td>Rank-sum versions of ANOVA</td>
</tr>
<tr>
<td>Continuous</td>
<td>Continuous</td>
<td>Spearman's rank correlation</td>
</tr>
<tr>
<td><strong>Contingency tests</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two valued</td>
<td>Discrete</td>
<td>No special test, see next entry</td>
</tr>
<tr>
<td>Discrete</td>
<td>Discrete</td>
<td>Contingency table and chi-squared test</td>
</tr>
<tr>
<td>Continuous</td>
<td>Discrete</td>
<td>(Rare) Group independent variable and then as above.</td>
</tr>
</tbody>
</table>
3.4 Chapter Summary

This chapter presented an overview of research methods relevant to this study. There are two main categories of research: qualitative and quantitative. Quantitative research refers to mainly hypothesis testing achieved through surveys and laboratory experiments. Results are usually interpreted using statistical analysis procedures. Qualitative research refers to the interpretive and natural study of phenomena in their natural setting using methods such as action research, case study, ethnography and grounded theory by collecting data through observation and interviews. As the purpose of this study is to determine whether results found in Koykka, et al. (1999) will be similar when applied in a non-immersive desktop photorealistic virtual environment, a heuristic evaluation, think-aloud protocol will be conducted and a variation of the grounded theory approach called emergent themes analysis will be used for analysis. Thus, a qualitative approach is appropriate in this study.

The next chapter will discuss some of the general usability evaluation methods.
Chapter 4    General Usability Evaluation

This chapter will look at usability evaluation with particular reference to evaluation methods such as heuristic evaluation and think-aloud protocols that will be used in this study. The chapter begins with an introduction of what is usability evaluation, why it is important and how it fits within the System Development Life Cycle (SDLC). Followed by, a section on various usability evaluation methods will be discussed.

4.1 Definitions of usability and usability evaluations

Evaluations or system testing had always been a part of the systems development life cycle. Although systems should be tested throughout the development life cycle, system testing is often conducted after the system has been designed and developed, and often, the system is tested for functionality. In the most cases, usability is defined as to whether the system is supposed to perform the way it should be rather than how intuitive is the system to use for the user.

Nowadays, functional systems are no longer enough. Systems need to also be usable. This means that the user is able to accomplish their tasks effectively and efficiently as possible due to the system being easy to learn, easy to use, and robust thus leading to user satisfaction. In previous years, usability has a variety of definitions. These definitions are presented below:

"[A usable system is]...one that supports the effective and efficient completion of tasks in a given work context (software system)."  (Karat, J. and Dayton, T. 1995)

"[Usability]...the degree to which the design of a device may be used effectively and efficiently by a human."  (Bailey, R. W. 1996)

"a measure of the ease with which a system can be learned or used, its safety, effectiveness and efficiency and attitude towards it."  (Preece, J., Rodgers, Y. et al. 1996)
Chapter 4: General Usability Evaluation

"how easy to learn the user interface is for a novice and a casual user. It is how easy it is to use (efficient, flexible and powerful) for frequent and proficient users after they have mastered the initial learning of the interface." (Mayhew, D. J. 1999)

"the effectiveness and efficiency of interaction among users, their tasks and the task environment." (Userworks.com 2002)

"it (tool) must allow the intended user to accomplish their task in the best possible way." (UsabilityFirst 2003)

From the above definitions, usability can be described to be the efficiency and effectiveness in which a user can use the system in order to achieve a specific goal. It also describes usability as possessing factors of ease of learning, robustness and satisfaction in use. With such an array of characteristic important to usability, the next section briefly states why usability evaluation is important in any system design.

4.2 Importance of usability evaluations

There are several reasons and benefits why a usability review should be conducted. The first section will briefly discuss some of the reasons why usability evaluations are important. The second section will briefly present the benefits of conducting a usability evaluation.

4.2.1 Why is usability evaluation important?

Usability evaluation is an important exercise to conduct. The reasons can be presented under three main categories: to assess system functionality, to assess user experience and to identify specific usability problems. Each one will be briefly discussed below.

4.2.1.1 To assess system functionality

Preece, J., Rogers, Y. and Sharp, H., (2002) states that without evaluation, designers cannot be sure that their software is usable and is what the user wants. Therefore, conducting a usability review is a way of confirming user requirements as developers and users often possess a different understanding and mental models of a particular system (Galitz, W. O. 2002). Furthermore, relying simply on design standards and guidelines or plain designer's intuition does not guarantee that the new system will enhance user performance when performing tasks.

4.2.1.2 To assess user experience

Usability evaluations are also important measures of user experience. Various methods and techniques such as direct observations and interviews allow for designers and developers to elicit feedback about the system before its full development and implementation. Assessing user experience is an important exercise to undertake as there are no average users (Galitz, W. O. 2002).
4.2.1.3 To identify specific usability problems

Another reason why evaluating for usability is an important exercise, is to be able to identify system problems (for example in the design stage) that contribute to a system’s usability. Galitz, W. O., (2002) states one of the reasons why usability evaluation is important is that it is often impossible to predict usability from just a system’s appearance. Furthermore, IBM UCD (IBMUCD 2003) stated that “for developers and manufacturers, the advantages of creating usable products far outweigh the costs. The rule of thumb: “every dollar invested in ease of use returns US$10-US$100”. Therefore, problems found later in the development life cycle are more difficult and expensive to fix compared than problems found or identified during development. The latter will mean reduced costs later, which can result to competitive advantage of that product.

4.2.2 What are the benefits of usability evaluations?

There are many benefits to conducting usability evaluations. Aside from the reasons stated above, undertaking usability evaluations, especially in the design phase, will help ensure the design of usable systems. Additionally, usable systems have result in positive benefits like increased productivity, increased accuracy of data input and interpretation, decrease in user training time and costs, decreased user errors and decrease of ongoing technical support (1999).

However, in order to ensure that usability is achieved, it is important to know about the different evaluation methods and techniques as different evaluations measure different things such as functionality of the system, user interface features, or timeliness. Furthermore, different evaluation methods are used in different stages of the development life cycle.

The different stages of the development life cycle (The Systems Development Lifecycle 2004) and an indication of where usability evaluation fit in is presented in the next section:

Specification

This stage defines the general requirements of the system such as its functions. Assessing the current system functionality will enable developers to understand why new functionalities are needed.

Possibly a feasibility study

The requirements for the system are examined and possible solutions are produced together with a cost/benefit analysis as a report. Identifying usability problems with the current system will allow developers to discuss different options to provide the best possible solution to the usability problem early on in the development life cycle. Thus reducing costs in re-development and maintenance after implementation (Dix et al., 2004).
Chapter 4: General Usability Evaluation

**Analysis**

If an existing manual or computerised system is to be improved then the existing system is investigated and documented in detail. By doing so, identifying current system problems that diminishes its' usability.

**Design and Development**

This is the planning stage for the new system. New hardware may need to be purchased, software purchased or written then installed, data files created or transferred. Users will need to be trained. A prototype model of the system may be built so that the buyer can explore the system to see whether it looks and feels okay. The specification may then be altered if necessary. This is an important stage to conduct usability testing, not only for functionality but also for user experience and further usability problems. It is at this stage where critical changes need to be made to reduce future costs in re-development and maintenance after implementation.

**Implementation**

The system is built following the design documents exactly. Any hardware or software required will be purchased and installed.

**Testing**

The system is run using test data so that any errors may be eradicated and enhancements made. System functionality testing is important to conduct at this stage.

**Evaluation**

Users will form an opinion of the system after a period of use. Perhaps certain functions don't work exactly as anticipated, or procedures take too long or are too complicated, or even discover omissions because they forgot to include them in the original specification. User experience, particularly about further usability problems need to be assessed at this stage.

**Maintenance**

This is when improvements are made to the system as needed such as the addition of new functions.

Iterative evaluation is important in designing usable systems with results from evaluations feeding back into the modification to the design (Dix, A., Findlay, J. E. *et al.* 2004). The following section presents various methods and techniques that may be used to evaluate the usability of a system.
4.3 Different evaluation methods and techniques

Knowledge about various evaluation techniques aids designers and developers to choose the most appropriate evaluation method or technique to use when conducting usability tests. There are many factors to be considered when choosing an evaluation method. Table 4-1 presents some of the questions and factors that need to be addressed when choosing an evaluation technique (modified from (Axup, J. 2002; Genise, P. 2002; Wong, B. L. W. 2001; Zhang, Z. W. 2003)):

Table 4-1. Questions and factors addressed when choosing an evaluation method (modified from Wong, 2001)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Factors that are addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is to be evaluated?</td>
<td>The functionality, the system responsiveness, the design</td>
</tr>
<tr>
<td>When should we evaluate?</td>
<td>Formative (design stage) vs. Summative (implemented system)</td>
</tr>
<tr>
<td>Where is it to be conducted? In a laboratory setting or in the field?</td>
<td>Context of actual use</td>
</tr>
<tr>
<td>Should the data collected be subjective or objective?</td>
<td>Extent to which collected data is interpretive, e.g., evaluator's observation vs. user task times</td>
</tr>
<tr>
<td>What is the nature of the data being collected? Is it qualitative or quantitative?</td>
<td>Nature of the data to be collected, e.g., description of concepts vs. learning time</td>
</tr>
<tr>
<td>How soon can the results be used?</td>
<td>Immediacy of the results</td>
</tr>
<tr>
<td>Will the procedure influence the results?</td>
<td>Intrusiveness – The extent to which the evaluator intrudes in the user's work and thereby affecting the outcome</td>
</tr>
<tr>
<td>What resources do I need?</td>
<td>Equipment such as pencil and paper, multi-angle video cameras, quad-splitter, high quality microphones.</td>
</tr>
</tbody>
</table>

It is important to consider the questions and factors above when choosing an evaluation method as different evaluation techniques measure different aspects of a system at different stages of system development. For example, evaluations conducted throughout the development life cycle can apply a formative evaluation technique like Goals, Operations, Methods and Selection Rules (GOMS) at the design stage. In contrast, evaluations conducted at the conclusion of product development uses summative evaluation techniques such as direct user observation and interviews. There are three types of usability evaluation methods: Testing, Inspection and Inquiry (Zhang, Z. W. 2003). The following section briefly describes each of the different evaluation methods according to its research method classification (qualitative or quantitative) and then type.

4.3.1 Usability Testing Evaluation Methods

In a usability testing approach, representative users work on typical tasks using the system (or the prototype) and the evaluators use the results to see how the user interface supports the users to do their tasks (Zhang, Z. W. 2003). Qualitative testing methods include think-aloud protocol, coaching method, discovery learning, question-asking protocol, remote testing, retrospective testing, and teaching method. Performance measurement is an example of a quantitative research method. Each testing method is briefly described in the next section.
4.3.1.1 Usability Testing Qualitative Research Methods

Think-Aloud Protocol

Think-Aloud Protocol (Zhang, Z. W. 2003) is a form of user testing where one user's interaction with a product is videotaped and analyzed to improve the product (Axup, J. 2002). During the course of a usability test, the participants are asked to verbalize their thoughts, feelings, and opinions while interacting with the system. It is very useful in capturing a wide range of cognitive activities, thus allowing the researcher(s) to understand how users view the computer system for early identification of user's major misconceptions (Nielsen, J. 1997). According to Nielsen, J. (1993), the two variations of think-aloud protocol techniques are:

- Critical response where the user is required to be vocal only during the execution of certain pre-determined sub-tasks; and
- Periodic reporting where the task is complex, making it difficult for users to think aloud while performing the task at the same time. The user, therefore, verbalizes at predetermined intervals of time and describes what he/she is currently trying to achieve. The length of the interval depends upon the complexity of the task. This technique is very time consuming, so it is recommended for subdivisions of a task.

Think-Aloud Protocol is conducted in the following way:

1. The researcher provides the participants with the product to be tested (or a prototype of its interface) and a set of tasks to perform.
2. The researcher asks the participants to perform the tasks using the product, and explain what they're thinking about while working with the product's interface.

The main benefit of the thinking aloud protocol is a better understanding of the user's mental model and interaction with the product: what the users are doing, why they are doing it while they are doing it and how they are doing it (Nielsen, J. 1997). It allows the user to express, in a sequence of steps, how they use the product to accomplish their task/goal. If the sequence is different from what is expected, then perhaps the interface needs to be revisited (Zhang, Z. W. 2003).

Many researchers have written about other benefits of think-aloud protocol. For example, the terminology the user uses to express an idea or function should be incorporated into the product design or at least in its documentation (Zhang, Z. W. 2003). This is a very close approximation to actual individual usage (Axup, J. 2002; Genise, P. 2002; Nielsen, J. 1997). There is also a wealth of qualitative data of vivid and explicit quotes collected from a fairly small number of users (Axup, J. 2002; Genise, P. 2002; Zhang, Z. W. 2003), where the suggested number of users is four, making it less expensive to conduct.
However, there are also some disadvantages to think-aloud protocol testing such as the testing environment not being natural to the user (Nielsen, J. 1997), and slowing the users down. The data may also provide a false impression of the user’s thoughts (Nielsen, J. 1997). Furthermore, transcribing the users’ "vivid and explicit quotes" (Nielsen, J. 1997) requires large amounts of effort.

**Coaching Method**

Coaching method involves interaction between the participant and the experimenter. The experimenter steers the participant in the right direction while using the system. During the test, the user can ask system-related questions and the experimenter will answer them to the best of their ability (Nielsen, J. 1997). One variation of the method involves a separate expert user serving as the coach, while the experimenter observes both the interaction between the participant and the computer, and the interaction between the participant and the coach.

The purpose of this technique is to discover the information needs of users in order to provide better training and documentation, as well as possibly re-design the interface to avoid the need for the questions. When an expert user is used as the coach, the expert user's mental model of the system can also be analyzed.

The experimenter can also control the answers to certain predetermined information. In an extensive series of experiments, one could vary the coach's answers in order to learn what types of answers helped users the most. But this requires skilled and careful coaches since they need to compose answers on the fly to unpredictable user questions (Zhang, Z. W. 2003).

This technique can be used in the following development stages: design, development, evaluation, and deployment.

**Co-discovery Learning**

During a co-discovery learning usability test, two participants attempt to perform tasks together while being observed. They are to help each other in the same manner as they would if they were working together to accomplish a common goal using the product (Nielsen, J. 1993). They are encouraged to explain what they are thinking about while working on the tasks. Compared to think-aloud protocol, this technique makes it more natural for the participants to verbalize their thoughts during the test (Dumas, J. S. and Redish, J. C. 1993).

This technique can be used in the following development stages: design, development, evaluation, and deployment (Zhang, Z. W. 2003).

**Question-asking Protocol**

During a question-asking protocol usability test, besides letting the participants to verbalize their thoughts as in the thinking aloud protocol, the researcher prompts them by asking direct questions about the product, in order to understand their mental model of the system and the
tasks, including where they have trouble in understanding and using the system. This is a more natural way than the think-aloud method in letting the participant to verbalize their thoughts. The technique can be used in the following development stages: development, evaluation, and deployment (Zhang, Z. W. 2003).

**Remote Testing**
Remote testing technique is used when researcher(s) are separated in space and/or time from the participants. This means that the researcher(s) cannot observe the testing process directly and that the participants are usually not in a formal usability laboratory. There are different types of remote testing. One is same-time but different-place, where the researcher can observe the participant's screen through computer network, and may be able to hear what the participant says during the test through speaker telephone. Another is different-time different-place testing such as journaled [sic] (Genise, P. 2002; Zhang, Z. W. 2003) sessions, where the user's test session is guided and logged through a special piece of software as well as additional code added to the system being tested (Zhang, Z. W. 2003). The technique can be used in the following development stages: development, evaluation, and deployment (Zhang, Z. W. 2003).

**Retrospective Testing**
Retrospective testing works by matching users' comments while reviewing the tape of the user while using the system (Nielsen, J. 1997). The researcher(s) can collect more information by reviewing the videotape together with the user participants and asking them questions regarding their behavior during the test. So this technique should be used along with other techniques, especially those where the interaction between the researchers and the participants is restricted. But using this technique means that each test takes at least two times as long (Zhang, Z. W. 2003). Another obvious requirement for using this technique is that the user's interaction with the computer needs to be recorded and replayed. The technique can be used in the following development stages: development, evaluation, and deployment (Zhang, Z. W. 2003).

**Shadowing Method**
During a shadowing method usability test, the researcher has an expert user (in the task domain) sit next to him/her and explain the participant's behavior to the researcher. This technique is used when it's not appropriate for the participant to think aloud or talk to the researcher while working on the tasks (Zhang, Z. W. 2003).

**Teaching Method**
During a usability test, users interact with the system first, so that they are familiar with the system and acquire some expertise in accomplishing tasks using the system. The researcher
then introduces a naive user to each participant. The novice users are briefed by the researcher
to limit their active participation and not to become "an active problem-solver". Each
participant is asked to explain to the novice how the system works and demonstrate to him/her
a set of pre-determined tasks. This technique can be used for the following development
stages: design, development, evaluation, and deployment (Zhang, Z. W. 2003).

4.3.1.2 Usability Testing Quantitative Research Methods

Performance Measurement
This technique is used to obtain quantitative data about participants' performance when they
perform the tasks during usability test (Nielsen, J. 1993). It usually involves testing of
individual or groups of components as they are being developed with the purpose of
determining whether the product or the process elicits the necessary level of human
performance to meet user requirements (Bailey, R. W. 1996).

The technique generally prohibits interaction between the participant and the experimenter
during the test that will affect the quantitative performance data. Performance measurement is
usually conducted in a formal usability laboratory so that the data can be collected accurately
and possible unexpected interference is minimized (Nielsen, J. 1993). Quantitative data is
most useful in doing comparative testing such as speed, error and training time data (Bailey,
R. W. 1996), or testing against predefined benchmarks. To obtain dependable results, at least
five user participants are needed, while 8 or more participants would be more desirable. The
technique can be used in combination with retrospective testing, post-test interview or
questionnaires so that both quantitative and qualitative data are obtained. The technique can
be used in the following development stages: development, evaluation, and deployment
(Zhang, Z. W. 2003).

4.3.2 Inspection Evaluation Methods

In a usability inspection approach, usability specialists – and sometimes software developers,
users and other professionals – examine usability-related aspects of a user interface (Zhang,
Z. W. 2003). Commonly used Inspection methods include: heuristic evaluation cognitive
walkthroughs, pluralistic walkthrough, perspective-based inspection and feature inspection
evaluation method is briefly described in the next section.

4.3.2.1 Inspection Evaluation Qualitative Research Methods

Heuristic Evaluation
Heuristic evaluation is an informal usability inspection method for finding usability problems
in a user interface by having a small set of evaluators examine an interface and judge its
compliance with usability principles (heuristics). This technique was developed by Rolf
Molich and Jakob Nielsen in 1990 in which experts guided by a set of heuristics, evaluate whether user interface elements, such as dialog boxes, menus, navigation structure, on-line help etc., conform to the usability and design principles (Molich, R. and Nielsen, J. 1990; Nielsen, J. and Molich, R. 1990). The original set of heuristics was derived empirically from an analysis of 249 usability problems of an invented telephone index system (Nielsen, J. 1994, 1997; Nielsen, J. and Mack, R. L. 1994; Preece, J., Rogers, Y. et al. 2002). The resulting observations represent an evaluator's opinion about what needs to be improved in a user interface (Preece, J., Rogers, Y. et al. 2002). Table 4-2 and Table 4-3 shows Nielsen’s heuristics including questions addressed when undertaking a system evaluation and the five-point severity rating scale for usability problems found.

### Table 4-2. Nielsen’s heuristics and questions to be addressed in a system evaluation (Preece, J., Rogers, Y. et al. 2002) p 408:

<table>
<thead>
<tr>
<th>Nielsen’s Heuristics</th>
<th>Questions addressed in the evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of system status</td>
<td>Are users kept informed about what is going on?</td>
</tr>
<tr>
<td></td>
<td>Is appropriate feedback provided within reasonable time about a user’s action?</td>
</tr>
<tr>
<td>Match between system and the real world</td>
<td>Is the language used at the user interface simple?</td>
</tr>
<tr>
<td>User control and freedom</td>
<td>Are there ways of allowing users to easily escape from places they unexpectedly find themselves in?</td>
</tr>
<tr>
<td>Consistency and standards</td>
<td>Are the ways of performing similar actions consistent?</td>
</tr>
<tr>
<td>Help users recognize, diagnose and recover from errors</td>
<td>Are error messages helpful?</td>
</tr>
<tr>
<td></td>
<td>Do they use plain language to describe the nature of the problem and suggest a way of solving it?</td>
</tr>
<tr>
<td>Error prevention</td>
<td>Is it easy to make errors?</td>
</tr>
<tr>
<td></td>
<td>If so where and why?</td>
</tr>
<tr>
<td>Recognition rather than recall</td>
<td>Are objects, actions and options always visible?</td>
</tr>
<tr>
<td>Flexibility and efficiency of use</td>
<td>Have accelerators (i.e. shortcuts) been provided that allow more experienced users to carry out tasks more quickly?</td>
</tr>
<tr>
<td>Aesthetic and minimalist design</td>
<td>Is any unnecessary and irrelevant information provided?</td>
</tr>
<tr>
<td>Help and documentation</td>
<td>Is help information provided that can be easily searched and easily followed?</td>
</tr>
</tbody>
</table>

### Table 4-3. Five-point rating scale for the severity of usability problems found by heuristic evaluation (Nielsen, J. 1994).

<table>
<thead>
<tr>
<th>Severity Rating</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – Disagree with the problem</td>
<td>I don’t agree that this is a usability problem at all.</td>
</tr>
<tr>
<td>1 – Cosmetic problem only</td>
<td>Need not be fixed unless extra time is available on project.</td>
</tr>
<tr>
<td>2 – Minor usability problem</td>
<td>Fixing this should be given low priority.</td>
</tr>
<tr>
<td>3 – Major usability problem</td>
<td>Important to fix, so should be given high priority.</td>
</tr>
<tr>
<td>4 – Usability catastrophe</td>
<td>Imperative to fix this before product can be released.</td>
</tr>
</tbody>
</table>

In addition to identifying heuristic violations and problems, severity ratings are also used to allocate the most resources to fix the most serious problems and also provide a rough estimate of the need for additional usability efforts (Axup, J. 2002; Nielsen, J. 1994).

The heuristic evaluation method is conducted in the following way:

i. The evaluators, first individually, examine the interface of the system. They go through the interfaces at least twice: first to get a feel of the system and second to understand what each dialogue does and is intended to do. Then, the participant evaluates the interface using the heuristics detailed in Table 4-2 by considering the goal to be achieved at each stage such as the task or sub-task.
ii. Only after all the evaluators have completed their individual evaluation, the evaluators discuss and aggregate their findings. They categorize and prioritize the problems based on an agreed severity rating found in Table 4-3. This procedure is important to ensure independent and unbiased evaluation from each evaluator.

There are many benefits to conducting a heuristic evaluation. It is not only inexpensive and quick to implement (Nielsen, J. 1994; Zhang, Z. W. 2002) but it also identifies a large proportion of interface problems with a small amount of expert evaluators. Nielsen’s experience indicates that around 5 evaluators usually result in about 75% of the overall usability problems being discovered as shown in Figure 4-1 (Nielsen, J. 1994; Preece, J., Rogers, Y. et al. 2002).

![Figure 4-1](image)

Figure 4-1. Curve showing the proportion of usability problems in an interface found by heuristic evaluation using various numbers of evaluators. The curve represents the average of six case studies of heuristic evaluation (Preece, J., Rogers, Y. et al. 2002).

However, there are some disadvantages to a heuristic evaluation. These include the validity of Nielsen’s heuristics and guidelines and its comparative merits with other guidelines such as Ben Shneiderman’s Eight Golden Rules of Interface Design and Donald Norman’s Seven Principles for Transforming Difficult Tasks into Simple Ones (Dix, A., Findlay, J. E. et al. 2004). Table 4-4 lists Shneiderman and Norman’s “Golden Rules and Heuristics”.

37
Table 4.4. Ben Shneiderman and Donald Norman’s “Golden Rules and Heuristics” for producing usable systems (Dix, A., Findlay, J. E. et al. 2004).

<table>
<thead>
<tr>
<th>Shneiderman’s Eight Golden Rules for Interface Design</th>
<th>Donald Norman’s Seven Principles for Transforming Difficult Tasks into Simpler Ones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strive for consistency in action sequences, layout, terminology, command use and so on.</td>
<td>Use both knowledge in the world and knowledge in the head.</td>
</tr>
<tr>
<td>Enable frequent users to use shortcuts.</td>
<td>Simplify the structure of tasks.</td>
</tr>
<tr>
<td>Offer informative feedback for every user action.</td>
<td>Make things visible.</td>
</tr>
<tr>
<td>Design dialogs to yield closure so that users know when they have completed a task.</td>
<td>Get the mappings right.</td>
</tr>
<tr>
<td>Offer error prevention and simple error handling.</td>
<td>Exploit the power of constraints.</td>
</tr>
<tr>
<td>Permit easy reversal of actions.</td>
<td>Design for error.</td>
</tr>
<tr>
<td>Support internal locus of control.</td>
<td>When all else fails standardize.</td>
</tr>
<tr>
<td>Reduce short-term memory load.</td>
<td></td>
</tr>
</tbody>
</table>

Furthermore, some of these core heuristics are too general for evaluating new products coming onto the market and thus, there is a strong need for heuristics that are more closely tailored to specific products (Axup, J. 2002; Genise, P. 2002; Preece, J., Rogers, Y. et al. 2002). For example, Nielsen (1999) (cited in Preece, J. et al., 2002, p409) suggests that for evaluating commercial websites, High-quality content, Often updates, Minimal download time, Ease of use, Relevant to users’ needs, Unique on-line medium, and Netcentric corporate culture or HOMERUN is more memorable and applicable. Heuristic evaluation can be applied during the design, development and deployment stage of the system development lifecycle.

**Cognitive Walkthroughs**

Cognitive walkthrough involves one or a group of evaluators inspecting a user interface by going through a set of tasks and evaluating its understandability and ease of learning. The user interface is often presented in the form of a paper mock-up or a working prototype, but it can also be a fully developed interface (Zhang, Z. W. 2003). The input to the walkthrough also include the user profile, especially the users' knowledge of the task domain, of the interface, and the task cases (Wharton, C. 1993). The evaluators may include human factors engineers, software developers, or people from marketing, documentation, etc. The evaluators focus on the cognitive processes and perceptions of the users to determine what changes should be made (Axup, J. 2002). This technique is best used in the design stage of development. But it can also be applied during the development, evaluation, and deployment stages (Axup, J. 2002; Zhang, Z. W. 2003).

**Pluralistic Walkthrough**

The pluralistic walkthrough involves a combination of evaluators. The participants are a group of users, usability engineers and product developers. The group meet together and discuss the usability of the system (Zhang, Z. W. 2003). Group walkthroughs have the advantage of providing a diverse range of skills and perspectives to bear on usability problems. Thus, the more people looking for problems, the higher the probability of finding usability and system problems. This is a characteristic of any inspection method. Also, the
interaction between the team during the walkthrough helps to resolve usability issues faster (Zhang, Z. W. 2003). A pluralistic walkthrough is applicable at the design stage of the system development lifecycle.

**Perspective-based Inspection**

Perspective-based inspection is where each inspection session focuses on a subset of usability issues covered by one of several usability perspectives. Each perspective provides the inspector a point of view, a list of inspection questions that represent the usability issues to check, and a specific procedure for conducting the inspection (Zhang, Z. W., Basili, V. et al. 1998). This technique can be applied at the design, test and deployment stage.

### 4.3.2.2 Usability Inspection Qualitative and Quantitative Research Methods

**Feature Inspection**

This inspection technique focuses on the feature set of a product. The inspectors are usually given use cases with the end result to be obtained from the use of the product. Each feature is analyzed for its availability, understandability, and other aspects of usability. For example, a common user scenario for the use of a word processor is to produce a letter. The features that would be used include entering text, formatting text, spellchecking, saving the text to a file, and printing the letter. Each set of features used to produce the required output (a letter) is analyzed for its availability, understandability, and general usefulness. Feature inspection technique can be applied at the development, evaluation, and deployment stage of the system development lifecycle (Zhang, Z. W. 2003). It can be both a qualitative and quantitative research method. Feature inspection can have users reporting on features verbally or measure the number of keystroke and mouse click it takes to achieve the required output.

### 4.3.3 Inquiry Evaluation Methods

Here, usability evaluators obtain information about users' likes, dislikes, needs and understanding of the system by talking to them, observing them using the system in real work (not for the purpose of usability testing) or letting them answer questions verbally or in written form (Genise, P. 2002; Nielsen, J. 1997). Inquiry evaluation methods include field observations, focus groups and interviews. Each inquiry evaluation method is briefly described in the next section.

#### 4.3.3.1 Inquiry Evaluation Qualitative Research Methods

**Interviews**

In this technique, human factors engineers formulate questions about the product based on the kind of issues of interest. Then they interview representative users to ask them these questions in order to gather information desired. It is good at obtaining detailed information as well as
information that can only be obtained from the interactive process between the interviewer and the user.

In an evaluation interview, an interviewer reads the questions to the user, the user replies verbally, and the interviewer records those responses. The methods of interviewing include unstructured interviewing and structured interviewing (Zhang, Z. W. 2003).

*Unstructured* interviewing methods are used during the earlier stages of usability evaluation. The objective of the investigator at this stage is to gather as much information as possible concerning the user's experience. The interviewer does not have a well-defined agenda and is not concerned with any specific aspects of the system. The primary objective is to obtain information on procedures adopted by users and on their expectations of the system.

*Structured* interviewing has a specific, predetermined agenda with specific questions to guide and direct the interview. Structured interviewing is more of an interrogation compared to unstructured interviewing, which is closer to a conversation.

Interview inquiry methods can be used during the design, development and implementation stage of the system development lifecycle.

**Field Observation**

Human factors engineers go to representative users' workplaces and observe them work, to understand how the users are using the system to accomplish their tasks and what kind of mental model the users have about the system. This method can be used in the test and deployment stages of the development of the product (Genise, P. 2002; Zhang, Z. W. 2003).

**Focus Groups**

This is a data collecting technique where about six to nine users are brought together to discuss issues relating to the system. A human factors engineer plays the role of a moderator, who needs to prepare the list of issues to be discussed beforehand and seek to gather the needed information from the discussion. This can capture spontaneous user reactions and ideas that evolve in the dynamic group process. This method can be used in the test and deployment stages of the development of the product (Axup, J. 2002).

**Questionnaires**

This inquiry method is less flexible than interviews, field observations and focus groups since questions are fixed in advance and are less probing (Dix, A., Findlay, J. E. *et al.* 2004). When using questionnaires, it is important to conduct a pilot study before mass distribution. By doing so, any problems with the questionnaire design can be addressed and then re-tested before distribution. Problems like misunderstanding of the questions and the time taken for the respondent to answer the questionnaire are some of the reasons why some questionnaires
fail. When conducting a pilot study, 4-5 users are usually asked to answer the questionnaire. Results are collected and analysed to see if questions were answered in the manner intended.

The main advantages of questionnaires include a wider participant group being reached, time taken to administer is considerably less than interviews or focus groups, option to rigorously analyze the data. Some disadvantages of using questionnaires include the low return rate (25-30%) and its distribution. Therefore, questionnaires need to be well designed and purposeful due to the lack of evaluator involvement when the user completes the questionnaire. For example, ‘what information is being sought?’, ‘how will the responses be analyzed?’, ‘Is the user providing specific measurable feedback on a particular interface or the user’s impression of the interface?’ Questionnaires can be administered at various points in the design process including during the requirements capture, task analysis and evaluation, in order to get information on the user’s needs, preferences and experience (Dix, A., Findlay, J. E. et al. 2004).

4.3.4 Comparison of Usability Evaluation Methods
There are many different usability evaluation methods available. The method chosen depends upon whether the method is supposed to test the system for user task support, inspect the user interface or to inquire about users’ opinions about the system. Table 4-5 summarizes the different usability evaluation methods discussed in this section based on Axup’s (2002) Comparison of Usability Evaluation Methods.
### Table 4-5. Usability Evaluation Methods Summary modified from (Axup, 2002).

<table>
<thead>
<tr>
<th>Evaluation Method Name</th>
<th>Evaluation Method Type</th>
<th>Conducted at the following System Development Life Cycle (SDLC) stage</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Thinking-Aloud Protocol | Testing                | Design, Development and Implementation                      | • 1 usability expert, 4 users  
• Participants in testing express their thoughts on the application while executing set tasks | • Uses less number of users therefore less expensive  
• Very close approximation to actual individual usage | • The environment is not natural to the user |
| Coaching Method         | Testing                | Design, Development and Implementation                      | • 1 usability expert, 4 users  
• Researcher steers the subject in the right direction while using the system; participant is allowed to ask questions and the researchers answers them | • User can easily ask questions and receive answers as they are performing tasks.  
• Researchers are provided with the user’s mental model as they use the system | • Requires skilled and careful coaches especially for unpredictable questions  
• Affect user’s performance |
| Co-discovery Learning   | Testing                | Design and Development                                       | • 1 usability expert, 6 users  
• 2 participants attempt to perform the tasks together and help each other out while trying to explain what they are thinking. | • More natural to verbalize their thoughts during the test. | • Differences in opinion and approach to the task between the participants |
| Question-asking Protocol| Testing                | Design and Development                                       | • 1 usability expert, 5 users  
• Participants verbalize their thoughts and answer direct questions from the researcher about the system. | • Understanding of the user’s mental model and tasks.  
• More natural than Thinking-Aloud Protocol | • Time consuming to administer |
| Remote Testing          | Testing                | Design, Development and Implementation                      | • The experimenter does not directly observe the users while they use the application. | • Efficiency, effectiveness and satisfaction, the three usability issues, are covered | • Additional Software is necessary to observe the participants from a distance |
| Retrospective Testing   | Testing                | Design, Development and Implementation                      | • 1 usability expert, 4 users  
• The researcher and the user review, often, video taped sessions of the user conducting the test after the user has performed the test. | • The ability for the experimenter to stop the tape and question the user in more detail without interference of the test.  
• It is more valuable when representative test users are hard to get hold of. | • It takes twice as long to conduct.  
• It can be expensive to conduct.  
• Powers of recollection fades with time. |
| Shadowing Method        | Testing                | Design, Development and Implementation                      | • 1 usability expert, 4 users  
• The researcher sits beside the user | • Clearly view how the user is using the system. | • The user may feel uncomfortable in performing the tasks with the researcher observing their movements. |
| Teaching Method         | Testing                | Design, Development and Implementation                      | • 1 usability expert, 6 users  
• A user first learns how to use the system. They are then asked to teach another “user” how to use the system | • The user learns about the main functionalities of the system | • The user may not have enough time to fully explore and learn about the system.  
• The “new user” who is an expert, may try to solve issues encountered by the user. |
| Performance Measurement | Testing                | Design, Development and Implementation                      | • 1 usability expert, 6 or more users  
• Formally administered test in a laboratory setting where there is no interaction between the user and the researcher to accurately collect quantitative data. | • Accurate results are obtained | • Time consuming to administer. |

---

* Development refers to the coding and testing of a system. Evaluation is otherwise stated to refer to just testing of the system for functionality, usability or both.
### Table 4-5. (continued) Usability Evaluation Methods Summary modified from (Axup, 2002).

<table>
<thead>
<tr>
<th>Evaluation Method Name</th>
<th>Evaluation Method Type</th>
<th>Conducted at the following System Development Life Cycle (SDLC) stage</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heuristic Evaluation</td>
<td>Inspection</td>
<td>Design, Development and Implementation</td>
<td>* 4 - 6 usability experts</td>
<td>* Uses experts</td>
<td>* The validity of Nielsen's guidelines have been questioned and alternative guidelines exist</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* HCI experts separately review an interface and categorize and justify problems based on a short set of heuristics (rules of thumb).</td>
<td>* Gives multiple reviewers common rules to site for justification of reviews</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* Reasonable fast</td>
<td></td>
</tr>
<tr>
<td>Cognitive Walkthrough</td>
<td>Inspection</td>
<td>Design, Development and Implementation</td>
<td>* Between 1-4 usability experts and 0-2 software developers.</td>
<td>* Good at refining requirements</td>
<td>* Does not address user satisfaction or efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* A team of evaluators walkthrough the application discussing usability issues through the use of a paper prototype or a working prototype.</td>
<td>* It does not require a fully functional prototype</td>
<td>* The designer may not behave as the average user when using the application</td>
</tr>
<tr>
<td>Pluralistic Walkthrough</td>
<td>Inspection</td>
<td>Design</td>
<td>* 1 usability expert, 1 software engineer, 2 users</td>
<td>* Usability issues are resolved faster</td>
<td>* Does not address the usability issue of efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* A team of users, usability engineers and product developers review the usability of the paper prototype of the application.</td>
<td>* Greater number of usability problems can be found at one time</td>
<td></td>
</tr>
<tr>
<td>Perspective-based Inspection</td>
<td>Inspection</td>
<td>Throughout</td>
<td>* The number is dependent on whose perspective is being evaluated.</td>
<td>* Issues identified can be addressed based on that user's perspective.</td>
<td></td>
</tr>
<tr>
<td>Feature Inspection</td>
<td>Inspection</td>
<td>Development and Implementation</td>
<td>* 1 usability expert</td>
<td></td>
<td>* This may bias the results as it is based on a certain point of view.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviews</td>
<td>Inquiry</td>
<td>Design, Development and Implementation</td>
<td>* 1 usability expert, 2 users</td>
<td>* Good at obtaining detailed information</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* The users are interviewed to find out about their experience and expectations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Observations</td>
<td>Inquiry</td>
<td>Evaluation and Implementation</td>
<td>* 1 usability expert</td>
<td></td>
<td>* Can not be conducted remotely</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* The researcher immerses themselves in the user's &quot;natural environment&quot;.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus Groups</td>
<td>Inquiry</td>
<td>Evaluation and Implementation</td>
<td>* 1 usability expert, 6 users</td>
<td>* Ability to observe first hand how users interact with the system in the context of their work and their environment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* A moderator guides a discussion with a group of users of the application.</td>
<td>* If done before prototypes are developed, can save money</td>
<td>* Obtrusive to the user.</td>
</tr>
<tr>
<td>Questionnaires</td>
<td>Inquiry</td>
<td>Throughout</td>
<td>* 1 usability expert that administers the questionnaire to the users.</td>
<td>* Uses a wider participant group.</td>
<td>* The environment is not natural to the user and may provide accurate results</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>* A pilot study needs to be conducted first to allow problems with the questionnaires to be ironed out before distribution</td>
<td>* Takes less time to administer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* Rigorous analysis available</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* Can be administered at various points of the SDLC</td>
<td></td>
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<td></td>
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</table>

Chapter 4: General Usability Evaluation
4.4 Chapter Summary

Usability is defined as the effectiveness and ease of use in which a user can use the system in order to achieve a specific goal. It is characterized by ease of use, learnability, efficiency, memorability and subjective satisfaction. There are various reasons as to why usability evaluations are essential to any system development. These reasons include testing for system functionality such as whether user requirements are met; assessing the way the user uses the new system for improvement and most importantly, to identify any issues arising from the proposed design of the system, which will save time and money. Usability evaluations should occur as early and as often as possible in every aspect of system design (formative) but evaluation once the product is complete is also important (summative). There are three main types of usability evaluation techniques: testing, inspection and inquiry. Some examples of usability testing methods include: thinking aloud protocols, coaching, co-discovery learning, and retrospective testing; inspection usability methods include heuristic evaluations, cognitive walkthroughs, and feature inspection; and inquiry methods include interviews, field observations, focus groups and questionnaires.

In this study, think-aloud protocol and heuristic evaluation will be used to evaluate the usability of desktop, photo-realistic virtual environments just like in Koyyka et al. (1999) study for non-immersive desktop 3D multi-user environments. See section 9.5.2.1 for discussion of possible alternative methods that could be used.

Chapter 5 will discuss the different aspects of usability within virtual environments particularly usability evaluations applied to virtual environments.
Chapter 5  Usability evaluation of virtual environments

5.1 Introduction

Over the years, we have seen the prolific use of Virtual Environments (VEs), not only in the popular area of entertainment (such as video games) and military simulations but also in medicine, art, marketing, engineering and construction. (Herndon, K. P., van Dam, A. et al. 1994; Stuart, R. 2001; Wickens, C. D., Gordon, S. E. et al. 1998). Yet with the advancement made in computing technology both in hardware such as faster processing chips and software such as various development and desktop applications to generate 3D models, the “ultimate” virtual reality still eludes developers. The definition of “ultimate” involves the feeling of presence and a high level of immersion, as described in Chapter 2, and so intuitive to use, efficient and effective in its delivery to be described as usable in Chapter 4. The overall effect should be that users cannot distinguish what is real and what is generated.

In order to understand what makes virtual environments usable, first, this chapter will look at characteristics that contribute to virtual environments. Next, current usability problems identified in literature of VE evaluations will be presented. Finally, the chapter will conclude with a brief summary regarding the focus of this study.

5.2 Virtual environment characteristics

There are many factors that contribute to an effective design and use of a virtual environment. These factors are within the domain of the physical (such as ergonomics of equipment), psychological attributes (like motion sickness and after effects), and technical (such as the hardware and software used to generate and use the VE system). Other features also describe a VE. These features are briefly described below.
Chapter 5: Interactions in Virtual Environments

According to Wickens and Barker (1995 cited in (Stuart, R. 2001)), the following features encompass a VE:

1. Three-dimensional (perspective and/or stereoscopic) viewing – a display representation that preserves the characteristics of the real world object.
2. Dynamic display (rather than static images) – it allows the users to view (and control) events dynamically in real-time.
3. Closed loop (interactive or learner-centered design, where the user is the active navigator as well as the observer) – there should be very little delay when users interact upon objects within the VE.
4. Inside-out (ego-referenced) frame of reference. The image of the virtual environment displayed is from the point of view of the user's head as it's positioned in the world.
5. Multimodal interaction using several input techniques and feedback through several sensory modalities like sound and tactile feedback.
6. HMD and tracking where the HMD tracks the head movement of the user and controls the view being presented

Furthermore, Stuart, R. (2001) states that virtual environments are consisted of objects, behaviours and interactions. Each one is described below:

5.2.1 Virtual environment components

5.2.1.1 Objects

There are many types of objects that can be incorporated into virtual environments. They can be represented as realistic (like that of photo-realistic VEs), scale-altered (realistic except their size has been changes), property altered, iconic, or abstract. Interactive objects also provide users with cues as to how they are supposed to work and use (affordances) just as real world objects do (Stuart, R. 2001). Objects can be created within a VE using text-based editors, Computer-Aided Design (CAD) modeling tools, or by digitization of real world objects like in this study. With most objects created in a VE, certain behaviors need to be assigned. This will be discussed next.

5.2.1.2 Behaviors

Objects present within a VE can be assigned to exhibit different behaviors depending on the requirements of the user. They can be made to change sound, color, visual texture and shape in response on the users action or state of the simulation (Stuart, R. 2001). These behavioral properties assigned to objects allow the users' to interact with them as if in the real world. Interaction with VE objects is an important component as behaviors. Interactions with VE objects will be discussed next.

5.2.1.3 Interactions

Interactions in virtual environments, in some respects, follow what is currently in use to interact with window-based, graphical user interfaces (GUIs). There are many types of interaction styles that can be used in VE(s). Although, the following definitions of interaction
styles apply to immersive virtual environments, some interactions can also be applied or re-defined to fit photo-realistic, desktop virtual environments. Interaction styles like navigation and wayfinding, selection and manipulation and system control will be discussed in detail in the following section.

**Navigation and wayfinding**

Virtual environment navigation is the planning and execution of travel through space, real or virtual, carried out with reference to external or internal representations of the space being travelled (Herndon, K. P., van Dam, A. *et al.* 1994; Saretto, C. J. 1997). It is the moving of oneself sequentially around an environment, deciding at each step where to go next based on the tasks and the parts of the environment seen so far (Bowman, D. A., Johnson, D. B. *et al.* 1999). In photo-realistic, desktop virtual environments like QTVR, navigation is achieved through “jumping” between nodes activated by hotspots.

Wayfinding is described as locating and orienting oneself in an environment (Stanney, K. M., Mollaghasemi, M. *et al.* 2003). It is the “ability to find a way to a particular location in an expedient manner and to recognize the destination when it is reached” (Peponis, J., Zimring, C. *et al.* 1990). There are two tactics that compose the process of navigating throughout an environment: searching and browsing (Saretto, C. J. 1997). Each one is briefly defined.

- Searching is the task of looking for a known target.
- Browsing is the task of looking to see what is available in the VE.

It is important to note that when navigating within a virtual environment that appropriate information about spatial structure of the VE and location of target objects should be provided (Kaur, K., Maiden, N. *et al.* 1999; Stanney, K. M., Mollaghasemi, M. *et al.* 2003). Without this, users are likely to have difficulties in locating their current and/or desired destinations. The design of a VE must therefore include appropriate visual cues and navigational aids, such as a compass or a map, to facilitate users’ acquisition of spatial knowledge (Bowman, D. A. 1999; Darken, R. P. and Sibert, J. L. 1996). Furthermore, when travelling in a VE, the users must effectively move about the environment to obtain different views and acquire an accurate “mental map” of their environment (Bowman, D. A. 1999; Stanney, K. M., Mollaghasemi, M. *et al.* 2003). In some QTVR photo-realistic, desktop virtual environments, the absence of a map makes it difficult for users to navigate and orient themselves and their current location. This is particularly true when there are more than one location and nodes in a QTVR environment.
Object selection and manipulation

Object selection and manipulation may be defined as the process of indicating to the visual object within an virtual environment to reposition, re-orient or query to find out more about that object (Sandra, L. 2002).

Object selection involves users designating one or more virtual objects for some particular purpose (for example deleting an object, invoking a command, or changing state). This is often followed by subsequent manipulation of specified objects (Stanney, K. M., Mollaghasemi, M. et al. 2003). Furthermore, the selection and manipulation methods incorporated into a VE design have a great impact on the effectiveness and efficiency on a user’s interaction. Basic interaction issues (such as not being aware of which object are active) appear to be more prevalent in VEs than in traditional direct manipulation interfaces (Stanney, K. M., Mollaghasemi, M. et al. 2003). According to Kaur (1999) cited in (Stanney, K. M., Mollaghasemi, M. et al. 2003) this is because VEs have yet to establish standards such as how to define active objects and develop more effective gesture and tracking techniques (Kalawsky, R. S., 1999; Bowman, 2000 cited in (Kalawsky, R. S. 1999)). Moreover, according to (Krapichler, C., Haubner, M. et al. 1999; Saretto, C. J. 1997) the current multimodal nature of interaction in VEs still presents some limited understanding of how to best present multiple outputs such as redundancy and intrusiveness and most importantly feedback for user actions. In some QTVR photo-realistic, desktop virtual environments, there is typically limited support for virtual object selection and manipulation. Usually virtual objects are embedded within a panoramic photo-realistic virtual environment, with hotspots indicating clickable areas.

System Control

System control is when the user reaches a decision to stop or explore other things by invoking a travel action (Flasar, J. 2000).

5.2.2 Summary for the virtual environments characteristic section

In this section, we described the different characteristics that encompass virtual environments. VEs are made up of objects that are assigned behaviors to allow users to exercise different interaction styles on objects within the virtual environment. These interaction styles include navigation and wayfinding, selection and manipulation and system control. VEs should contain characteristics that are the same or similar to that of the real world in terms of dynamic views, actions and reactions that are delivered multi-modally to the user. The next section will briefly discuss findings from usability evaluations of virtual environments, with particular emphasis on desktop, photo-realistic systems, think-aloud and heuristic evaluation methods.
5.3 Koykka et al's study and other usability evaluations of virtual environments

5.3.1 Usability evaluations of VRML-based virtual environments

Traditional GUI usability relies on heavily researched and proven tools and heuristics in ensuring effectiveness, efficiency, and user satisfaction (Stuart, R. 2001). VE system usability, on the other hand, is just beginning to receive the focused attention needed for identifying a taxonomy of VE-specific usability attributes (Kalawsky, R. S. 1999). Traditional evaluation techniques (Kalawsky, R. S., Bee, S. T. et al. 1999; Nielsen, J. 1993; Stanney, K. M., Mollaghanemi, M. et al. 2003) do apply to virtual environments. However, these evaluation techniques were found not to be comprehensive enough to characterize usability attributes specific to three-dimensional (3D) spatially immersive and interactive environments such as virtual (Wilson, J. R. 1999). Most VE user interfaces are fundamentally different from traditional GUIs, with unique input/output (I/O) devices, perspective, and physiological interactions. Thus, when developers and usability practitioners attempt to apply traditional usability engineering methods to the evaluation of VE systems they find few, if any, that are particularly well suited to these environments (Hix and Gabbard, 2002 cited in Stanney, K. M. et al., 2003).

Subsequently, very few principles for design of VE user interfaces exist, of which none are empirically derived or validated (Bowman, D. A., Johnsen, D. B. et al. 1999; Dalgarno, B. and Scott, J. 1999; Darken, R. P. and Sibert, J. L. 1996; Kalawsky, R. S. 1999; Kaur, K., Maiden, N. et al. 1999). Furthermore, there is no clear indication from any research that usability evaluation of large- or small-scale non-immersive desktop, photo-realistic QTVR virtual environments have previously been conducted. This study, hopes to initiate an additional thread of discussion.

While limited work on VE usability has been conducted to date, there are early works that have attempted to improve VEs from users’ perspective by integrating a systematic approach to VE development and usability evaluation (Dede, C., Salzman, M. et al. 2000). By addressing key characteristics unique to VEs, their work has identified limitations of existing usability methods for assessing VE systems as presented in Table 5-1.

<table>
<thead>
<tr>
<th>Limitations of traditional usability methods for assessing virtual environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional point and click interactions are not representative of the multi-dimensional object selection and manipulation characteristics of 3D spaces.</td>
</tr>
<tr>
<td>Quality of multimodal system output (e.g. visual, auditory, haptic) is not comprehensively addressed by traditional evaluation techniques.</td>
</tr>
<tr>
<td>Means of assessing sense of presence and after-effects have not been incorporated into traditional usability methods.</td>
</tr>
<tr>
<td>Traditional performance measurements (such as time/accuracy) do not comprehensively characterize VE system interaction.</td>
</tr>
<tr>
<td>Traditional single user-task-based assessment methods do not consider VE system characteristic in which two or more users interact in the same environment.</td>
</tr>
</tbody>
</table>

In 1999, Koykka, and colleagues conducted an evaluation study that compared the suitability of Nielsen’s heuristics on 3-Dimensional (3D) worlds. User testing (including think-aloud protocol and interview) and heuristic expert evaluations were conducted. The results found that Nielsen’s heuristics were limited in a 3D world and that a combination of using a think-aloud protocol for user task tests and expert evaluation, additional categories were suggested in order to address the usability problems related in 3D environments. These three categories were (in order of importance) (Koykka, M., Ollikainen, R. et al. 1999):

- 3D environments should provide support for orientation, navigation and movement – providing feedback and support such as a start-up screen to explain the basic ways to move and use of functionalities would solve the inefficient way of accessing the different web services and content.
- Real world metaphors have to be clearly understandable – functional consistency and analogies with the real world should be self-explanatory and would help facilitate the learning process of use of the available services.
- Avoidance of delay and waiting periods in performance.

This paper is the basis of this research. The fundamental premise of this study is to determine whether additional usability categories will also result when applied in a desktop, photo-realistic virtual environment. In order to determine this, other usability issues with VEs particularly in desktop photo-realistic systems need to be reviewed.

The remaining sections will present and relevant literature of findings of usability evaluation methods previously used in order to identify problems found in VEs.

5.3.1.1 Theoretical models of interactions

Kaur, et al. (1999) stated that there is a need for interface design guidance for virtual environments, in order to avoid common usability problems. To develop such guidance, an understanding of user interaction is required (Kaur, K., Maiden, N. et al. 1999). Theoretical models of interaction with virtual environments were proposed. The models were evaluated through user studies, namely the task-action model, the explore-navigate model and the system initiative model. It was found that users utilized certain actions much more than others.
and this allowed a picture to develop of ways in which users view and interact with a VR world. For example, some stages in the interaction were missed out altogether, while at other times there was some backtracking to previous stages. It was concluded that these findings be used in order to refine the theoretical models of interaction to help create interface design guidelines for VR. Some of these theoretical interactions will be used in this study.

5.3.1.2 User-related design issue

Next, Mills and Noyes (1999) presented an overview of user-related design issues of virtual reality. They stated that due to the lack of design methods available for VR systems, it is difficult to design usable VRs. Furthermore, they stated that some of the generic design issues identified from human factors and technological perspectives are applicable to VRs (Mills, S. and Noyes, J. 1999). They include issues like the ability of the users to totally move around objects so that the back of an object can be viewed in the same way as the front, texturing and shadowing problems to ensure images look life-like and help for users especially as they use the system. They further suggest that specific design issues for non-immersive VEs include the users’ need to visualize the necessary movement of the object using the interaction device in order to give the user the perception movement. There are also issues of parallax as the user views the object on the screen as well as visual inaccuracy of distances, object textures and depth resulting from visual strain or increase in cognitive load. Visual strain and cognitive load may result in undetectable time lapses for the user. This may further result in the user becoming gradually frustrated as s/he struggles to apply the missing cues.

5.3.1.3 Experienced versus Novice GUI users

Dalgarno and Scott (1999) stated results from user testing and questionnaire indicate that some older users have difficulty in navigating through a 3D world, compared to users with graphical experience. This may be due to the shift from command environments to direct manipulation environments in the 1980s has helped graphical users to easily apply their direct manipulation experience to virtual environments. Thus making it easier to navigate for graphically experienced users (Dalgarno, B. and Scott, J. 1999).

5.3.1.4 VR Guideline Questionnaires

There was some development in developing evaluation methods and standards specific for VEs. An example is Kalawsky (1999), who developed a special questionnaire called VR Usability Questionnaire (VRUSE), which measures the usability of a VR system according to the attitude and perception of its users. It was developed using traditional human factor issues and usability results from the UK Engineering and Physical Science Research Council (ESPRC 2004) funded research. Examples of such research included the ESPRIT and MUSiC project, aimed to develop methods and tools for measuring usability with analytic metrics.
performance metrics, cognitive workload metrics and user satisfaction. Kalawsky’s analysis of the MUSIC framework indicated that certain components could be applied to evaluating highly interactive systems like VRs. There were ten usability factors and goals derived from nearly 250 questions and discussions from VR experts and users. Table 5-2 presents a list of usability factors and goals developed for VRUSE.

Table 5-2. Questionnaire design of Usability Factors and goals from VRUSE (Kalawsky, R. S. 1999)

<table>
<thead>
<tr>
<th>Usability Factors</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>The interface should be able to provide the level of functionality (control) the user expects in order to complete a task.</td>
</tr>
<tr>
<td>User input</td>
<td>The user should be able to interact with and control the virtual environment in a natural manner.</td>
</tr>
<tr>
<td>System output (display)</td>
<td>Information displayed to the user should be understood, unambiguous and necessary to complete the task.</td>
</tr>
<tr>
<td>User guidance and help</td>
<td>The user should be able to request help via on-line assistance.</td>
</tr>
<tr>
<td>Consistency</td>
<td>The operation of a VR system should be consistent with the user’s understanding and convention.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>The VR system should not constrain the user who should be able to interact with the system in a flexible manner.</td>
</tr>
<tr>
<td>Simulation fidelity</td>
<td>In order to be useful a VR system needs and underlying model or simulation to control the virtual environment.</td>
</tr>
<tr>
<td>Error correction/handling and robustness</td>
<td>All computer systems should provide error correction and recovery before a permanent change is made.</td>
</tr>
<tr>
<td>Sense of immersion/presence</td>
<td>A VR system should allow users to feel part of (or immersed in) a virtual environment.</td>
</tr>
<tr>
<td>Overall system usability</td>
<td>Overall, a VR system should be intuitive and easy to use.</td>
</tr>
</tbody>
</table>

Each of these factors was assessed using established statistical principles. In this case, a five-point Likert attitude scale was used to assign the following values (Figure 5-1):

<table>
<thead>
<tr>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>Agree</td>
<td>Undecided</td>
<td>Disagree</td>
<td>Strongly Disagree</td>
</tr>
</tbody>
</table>

Figure 5-1. A five-point Likert attitude scale used in VRUSE (Kalawsky, R. S. 1999)

The VRUSE questionnaire looked promising with its identification of various problematic aspects of VR systems. However, a more systematic research using the current VRUSE questions needed to be conducted for its refinement. Some aspects of the VRUSE questionnaire will be referred to in this study.

Recently, Stanney, et al. (2003) published a comprehensive list comprising of Multi-criteria Assessment of Usability for Virtual Environments (MAUVE). This two-stage, heuristic evaluation-type and validation exercise provided a structured approach to achieving usability of VE system design and evaluation with usability design considerations for interactions (wayfinding, navigation, object selection and manipulation), multi-modal system output (visual, auditory, haptic) and side effects were included (Stanney, K. M., Mollaghasemi, M. et al. 2003). Like Kalawsky (1999), VRUSE, although MAUVE provides design guidelines for VEs, more application testing and refinement is still needed before it becomes standard.
5.3.1.5 Wayfinding in Large 3D Virtual Worlds

Rudolph Darken and John Sibert (1996) conducted a study to determine whether real world wayfinding strategies by people, such as use of organizational principles like landmarks, paths, districts etc and map principles were used to wayfind in large virtual worlds.

Wayfinding is classified into three tasks: naïve search (no prior knowledge of the target, thus the user must perform an exhaustive search), primed search (the navigator knows the location of the target, thus the search is non-exhaustive) and exploration (where there is no target to find). The results showed that the lack of directional cues and spatial organization in the large VE with no wayfinding assistance such as a grid, map or both led to the ineffective search strategies and frequent disorientation. The radial grid provided enough information to successfully execute a search but required reinforcing actions to maintain orientation. The map provides a simultaneous geo-centric (location of the user relative to the map) perspective augmenting the egocentric (location of the user in the VE) perspective and fostering the use of geographical landmarks and optimization of search methods. There were six conclusions were drawn from this research. These are as follows:

1. Disorientation will inhibit both wayfinding performance and spatial knowledge acquisition without adequate directional cues.
2. A large VE world without explicit structure is difficult, if not impossible to search exhaustively. This was shown by repeated re-acquisition behaviour in the control treatment (no wayfinding assistance provided).
3. A structure must be imposed on the VE world if an organized exhaustive search is to be attempted as conceptual coordinate system is often imposed on the world, which acts as a divider is not present or limited in the VE world.
4. Subjects frequently used features such as coastlines or grid lines as if they were paths; supporting the notion that path following is a natural spatial behaviour.
5. A map allows for optimizations to be made to search strategies. This is because it can be considered a supplement to survey knowledge.
6. Dead reckoning was observed to be intuitive and natural part of navigation; all subjects exhibited the behaviour even though frequently unaware of it. The ability to infer position from a past location and constant velocity over time, while sometimes complex in reality, appears to be more easily understood and implemented in virtual spaces.

5.3.2 Usability evaluations of VRML-based and QTVR virtual environments

5.3.2.1 Task performance, navigation and subjective satisfaction

Johnson (1998) evaluated four desktop VEs, three VRML-based and one QTVR photo-realistic-based systems, for task performance, successful navigation and subjective satisfaction using some unmentioned heuristic criterion, think-aloud protocol, questionnaires and interviews. Johnson (1998) reported the following findings:
Similar difficulties for task performance, navigation and subjective satisfaction were found with VRML that with QTVR.

Users reported few difficulties in navigating both the VRML model and image mapped interface.

VRML browsers were counter-intuitive especially to users with no experience in navigating 3D environments using keyboard and mouse. Difficulties such as traversing within the VE.

Users expressed considerable frustration when navigating even though they stated desktop VR systems were "straight forward" in post-hoc questionnaires. This was more obvious when performing a think-aloud on the VRML-based system. Users also contradicted their comments but "cannot explain exactly what they do or don't like about desktop VR.

Furthermore, Johnson identified three criteria that might be used to assess utility of desktop VR:

- There must be a clear contribution from the 3D model of visualization to the user's task.
- The interface's browsing facilities must enable users to quickly traverse and manipulate the scenes and objects that the new technology provides.
- Users should exhibit strong subjective satisfaction ratings in support of the application of desktop VR systems.

5.3.3 Usability evaluations of QTVR virtual environments

5.3.3.1 Hotspot feedback, detailed help

With regards to evaluations and usability problems in photo-realistic VEs, Xiao's (2000) investigation and illustration of the potential use of photo-realistic panorama virtual reality in a web-based library resulted in the implementation of a system described as "useful medium that allows navigating, viewing, reading, hearing and remote access". A think-aloud protocol system evaluation was used to provide useful user insight into the draft design of the working system.

There was no specific list of common user concern provided within this literature but the author stated that among the common user concerns identified, was difficulty in finding information within the associated hotspots such as their location and the number of hotspots available (Xiao, D. Y. 2000). However, identification of usability problem resulted in a re-design of the system with feedback incorporated in hotspots and detailed help being added to the system. Xiao also stated that, in retrospect, visible aids such as an arrow or index finger icon or a dissolved dot could also have been incorporated in the scene as a hotspot indicator, without distorting the original look (Xiao, D. Y. 2000).
5.3.3.2 Eight Activity Breakdowns

A relevant study using Cognitive Task Analysis (CTA) and Activity Theory (AT) methodology was done by Norris in 2001. Norris's (2001) research into naïve wayfinding within a QuickTime Virtual Reality (QTVR) environment resulted in determining that navigational aids such as maps and landmarks, like signs, do enhance naïve wayfinding in terms of finding a particular point within the VE, object or place, respectively. Furthermore, the study also resulted in identifying eight common breakdowns (Norris, B. E. 2001). The eight breakdowns identified were:

- Location of Hotspots
- Size of Hotspots
- Difficulty in finding the starting point
- QTVR Default Zoom Level
- Access to All Areas of VE
- Orientation of Map
- Different Jump Distances
- QTVR Panning Speed

These are some of the problems that will be looked for in this study.

5.3.3.3 Natural and logical navigation, hotspot size and location

Similarly, Villanueva and Wong (2001), some of the interaction and design issues encountered when creating a photo-realistic panorama tour was discussed. Aside from the photographic issues encountered when creating the multi-node tour, two main interaction issues arose. Issues of provision of paths that are different actual paths and user navigation, usability, and landmarking were among those identified (Villanueva, R. and Wong, B. L. W. 2001). Each one is briefly described below:

1. Planning a natural and logical navigation between nodes.

Navigation through a QTVR virtual world consists of a series of 'jumps' between nodes. These jumps can be disorientating if the nodes are not selected appropriately. While familiarity with the local area helps in defining appropriate nodes, this raises a number of important VR interaction design issues. Some of the questions raised include:

- How far apart should the jumps be? What is the maximum distance between nodes (more nodes cost more to produce) so as to reduce the total number of nodes?
- What features of the destination nodes should be visible?
Chapter 5: Interactions in Virtual Environments

- What insight and local knowledge should be incorporated into the node to help users navigate through it without getting lost?
- What key features of the physical locality should be used to help provide natural affordances that can be tied to hotspots in the VR to guide a user through the virtual environment?

2. Navigation and hotspot size and location

In terms of user navigation and hotspot size and location, Norris (2001) issues are closely associated, like size and placement of the hotspots in the VR. An earlier study showed that placement and size of the hotspot influences what the user sees and where they go (Norris, B. E. and Wong, B. L. 2000). It indicated that as the user "jumps" from one node to the other they need to remember and recall where they have been and how to get back. In the Norris and Wong experiment, small size and non-obvious placement of these hotspots, for instance, led to the hotspots being difficult and time consuming to find. This raises a number of issues in designing for interaction:

- Where should hotspots be located? Should they be co-located in with actual objects of the environment?
- How should the hotspots be made obvious without distracting the user from enjoying the visual experience? For example, incorporating navigation aids such as text that say "From X to Skyline Y" or "To the Y from the X", while helpful, they tend to reduce the user experience by potentially obscuring the view.
- Would a simpler text-based "signposts" such as the "From - To" notation make it more conceptually intuitive for a user to come from a particular location and to go forward to another location? What color, e.g. black-on-white or white-on-black labels? What font size? Should legends be used instead?
- Should the user be made to actively seek out the hotspots, or should the hotspots reveal themselves in a non-intrusive manner? If so, how?
- What kind of feedback should be provided to the user when attempting to locate these hotspots?

5.3.4 Complexity of Information Systems

Every information system must have a certain degree of complexity in order to be able to perform its functions. However, a complex system is more difficult to understand, analyze, and change than a simpler one. Complexity of something "is defined as the effort (as it is perceived) that is required to understand and cope with" (Backlund, A. 2003) due to our limited cognitive abilities (Langfors, 1995 cited in (Backlund, A. 2003). Furthermore, Yates (1978 cited in (Backlund, A. 2003)) stated that there are five attributes to complexity: (1)
significant interactions; (2) high number (of parts, degrees of freedom, or interactions); (3) nonlinearity; 4) broken symmetry; and (5) nonholonomic constraints. Brewer (1973 cited in (Backlund, A. 2003)) also stated that “as a model’s elements become increasingly interconnected, it becomes increasingly complex.” Based on the descriptions above, it would suggest that the larger a system is, the more complex they get. Furthermore, it also suggests that simple systems are easier to use. However, too basic a system may limit the users ability to perform their tasks. Backlund (2003) also suggests that in any information system, that some degree of complexity is expected in order for users to perform their tasks.

With regards to the evaluation of large- versus small-scale VE systems, there is no clear indication from any research that a usability evaluation between large- or small-scale VE systems, immersive or non-immersive, has been previously conducted. With this in mind, complexity evaluation of the large- and small-scale non-immersive desktop photo-realistic VEs will be based on the definition and characteristics previously stated.

5.4 Chapter Summary

There are several relationships between presented literatures. Various researchers found that traditional usability evaluation methods are limited when evaluating virtual environments. However, it was not a futile exercise as these evaluations have not only found many usability issues but also aided in developing VE usability design and evaluation techniques like VRUSE and MAUVE. Although such design and evaluation principles exist, testing and refining are still needed. Thus, awareness and knowledge of current usability design, interaction issues and evaluation methods is still required.

As stated earlier in the chapter, the purpose of this study is to determine whether evaluation methods used in Koykka, M., Ollikainen, R., Ranta-aho, M., Milszus, W., Wasserroth, S. and Friedrich, M. (1999) will result in additional usability categories when applied in a desktop, photo-realistic virtual environment. To determine this, components of virtual environments were reviewed. The review included VE design and interaction principles, current usability design, interactions and evaluation methods issues. Issues like the need to provide support for orientation, navigation and movement, appropriate help and feedback are some examples that need to be considered in this study.

Chapter 6 will discuss the various research techniques that will be used in this study.
Chapter 6  Research methods used in this study

6.1 Introduction

This chapter outlines the qualitative evaluation methods that will be used in this study. As stated earlier, there are three objectives to this study:

First, to determine whether applying the same usability evaluation methodologies of think-aloud protocol analysis, interviews and heuristic evaluation tested by Koykka, et al. (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would also produce additional usability guideline categories.

Second, to determine whether think-aloud protocol or usability heuristic evaluation is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environments.

Third, to determine whether large-scale non-immersive, desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments.

6.2 Implications for the current study

In order to address the research objectives, an appropriate evaluation methodology is needed. The evaluation methodology used by Koykka, et al. (1999) discussed in Chapter 5 has been adopted and modified for purposes of this research. The goal of the Koykka et al. (1999)
evaluation was to compare the suitability of Nielsen’s heuristics on the evaluation of 3-Dimensional (3D) worlds based on user testing and expert evaluations.

From the evaluation, the results indicate that Nielsen’s heuristics was limited in a 3D world and that through using a think-aloud protocol for user task tests and expert evaluation, three additional categories were suggested in order to address the usability problems related in 3D environments (Koykka, M., Ollikainen, R. et al. 1999; Molich, R. and Nielsen, J. 1990; Nielsen, J. and Molich, R. 1990). Based on this research, the idea to compare the suitability of Nielsen’s heuristics on the evaluation of desktop photo-realistic virtual environments based on user testing through expert evaluations and think-aloud protocols was derived.

The following section will describe the techniques that will be used to elicit and analyze data in determining whether using Nielsen’s heuristics and using the think-aloud method would produce the same result when applied in a desktop photo-realistic virtual environment.

6.2.1 Heuristic Evaluation

As described in Chapter 4, heuristic evaluation is an informal usability inspection method of finding usability problems in a user interface by having a small set of expert usability evaluators examine an interface and judge its compliance against usability principles also known as heuristics. The technique was developed by Jakob Nielsen and Rolf Molich (Nielsen, J. 1994) in which experts guided by a set of usability principles known as heuristics, evaluate whether user interface elements of an invented telephone index system conform to usability and design principles. The following section describes the process of conducting a heuristic evaluation.

As briefly described in Chapter 4, heuristic evaluation is a two-step process.

1. Individual Inspection - the evaluators, first individually, examine the interface of the system. Each evaluator inspect the interfaces at least twice:
   i. First, the evaluator goes through the system to get a feel of interaction flow and the general scope of the system - how the system is supposed to work.
   ii. Second, the evaluator focuses on specific elements while knowing how they fit in the bigger picture – some understanding of what each dialogue does and is intended to do.
   iii. Third, each participant evaluates the interface using Jakob Nielsen’s heuristics detailed in Table 6-1. Whilst doing so, each participant considers the goal to be achieved at each stage such as the task or sub-task. The evaluator also assigns a severity rating, as described in Table 4-3.

This means that each participant records the task they are trying to achieve, the area of the interface being evaluated, and the heuristic(s) violated with examples as evidence. The list
is compiled. Typically, an individual heuristic evaluation lasts between an hour and two hours. Table 6-2 shows sample results from evaluating a non-immersive desktop photo-realistic VE called Wroxton Abbey using Nielsen’s 10 heuristics from Table 6-1.

**Table 6-1. Nielsen’s Usability Heuristics (Nielsen, J. 1997)**

<table>
<thead>
<tr>
<th>Heuristic Name</th>
<th>Nielsen’s Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of system status</td>
<td>The system should always keep users informed about what is going on, through appropriate feedback within a reasonable time.</td>
</tr>
<tr>
<td>Match between the system and the real world</td>
<td>The system should speak the user's language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. It should follow real-world conventions, making information appear in a natural and logical order.</td>
</tr>
<tr>
<td>User control and freedom</td>
<td>Users often choose system functions by mistake and will need a clearly marked “emergency exit” to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.</td>
</tr>
<tr>
<td>Consistency and Standards</td>
<td>Users should not have to wonder whether different words, situations, or actions mean the same thing in different contexts. Follow platform conventions.</td>
</tr>
<tr>
<td>Error Prevention</td>
<td>Even better than good error messages is a careful design, which prevents a problem from occurring in the first place.</td>
</tr>
<tr>
<td>Recognition rather than recall</td>
<td>Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for using the system should be visible or easily retrievable whenever appropriate.</td>
</tr>
<tr>
<td>Flexibility and efficiency of use</td>
<td>The system should cater to both inexperienced and experienced users. Allow users to tailor frequent actions. For example, accelerators (e.g. Hot Keys) -- unseen by the novice user -- may often speed up the interaction for the expert user.</td>
</tr>
<tr>
<td>Aesthetic and minimalist design</td>
<td>Dialogue boxes should not contain information, which is irrelevant or rarely needed. Every extra unit of information in a dialogue box competes with the relevant units of Information and diminishes their relative visibility.</td>
</tr>
<tr>
<td>Help users recognize, diagnose and recover from errors</td>
<td>Error messages should be expressed in plain language (no codes), precisely indicate the problem, and suggest a constructive solution.</td>
</tr>
<tr>
<td>Help and documentation</td>
<td>Although it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out and not be too large.</td>
</tr>
</tbody>
</table>

The following sections briefly show sample results from evaluating a desktop photo-realistic virtual environment called Wroxton Abbey using Nielsen’s ten heuristics.

**Table 6-2. ‘Snapshot’ of evaluators’ actual results from evaluating a desktop photo-realistic virtual environment called Wroxton Abbey using Nielsen’s ten heuristics**

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Heuristic(s) Violated</th>
<th>Description Problem</th>
<th>Severity</th>
</tr>
</thead>
</table>
| Main Page
http://www.wroxtonabbey.org/tour.html | 2 | The user does not know that they need to click on the “Foot Path” pole in order to start the virtual tour. | 4 |
| Instructions Page
http://www.wroxtonabbey.org/instructions.html | 2, 10 | Some instructions were missing especially to say that the user needs to hold and drag the mouse left to right in order to pan around the VR. | 4 |

2. Group Results Aggregation - only after all the evaluators have completed their individual evaluation, the evaluators discuss and aggregate their findings.

i. All individual results are presented to the group.

ii. Individual issues are then discussed and categorized into different usability problems.
iii. The number of times the same issue is presented by each individual evaluator is tallied under frequency of the problem.

iv. Criticality, the impact of the identified problem onto the usability of the system is discussed, determined and assigned by the group.

v. Finally, a severity rating (defined in 0) is then assigned based on the frequency and criticality of the problem. This determines which usability issues need immediate solutions.

Furthermore, while assigning each issue with a severity rating, combination of three factors need to be considered:

- The frequency with which the problem occurs: Is it common or rare?
- The persistence of the problem: Is it a one-time problem that the users can overcome once they know about it or will users repeatedly be bothered by the problem?
- The impact of the problem if it occurs (criticality): Will it be easy or difficult for the users to overcome?

This procedure is important to ensure independent and unbiased evaluation from each evaluator.

Keeping to the example of the Wroxton Abbey, Figure 6-1 shows an actual sample of collated group results from a heuristic evaluation.

![Figure 6-1. Individual Heuristic Evaluation Results aggregated into Group results from a desktop, photo-realistic virtual environment.](image-url)
6.2.2 Think-aloud protocol

Think-Aloud Protocols (or verbal protocols) are often used when trying to identify how people use an interface or toolset. Participants are asked to speak aloud as they work through some task. Each choice used, button pressed, etc. is verbalised, as well as what the participant is looking at during the process. All sessions are usually video recorded and analysed later. This technique has both positive and negative aspects. It is a good technique to use when trying to ascertain if there is a particular problem within an interface or when there is a process change and measurement of learning time is required. However, there may be unexpected results primarily because people are not used to slowing down their thinking to allow for speech.

As briefly described in Chapter 4, think-aloud protocol is conducted in the following way (Genise, P. 2002):

i. The development team organizes a list of tasks that the user needs to accomplish.

ii. The team organizes a small number of users (about 4 users).

iii. The researcher meets with the users.

iv. The researcher provides the users with a prototype or interface of the application as well as a list of tasks.

v. The researcher requests that the user state his/her thoughts while performing each of the tasks.

vi. The researcher notes any changes that should be considered when revising the design application.

For example, Xiao (2000) used a think-aloud protocol to evaluate his created desktop photo-realistic virtual environment library for Texas A & M University for usability. He asked a non-technology-oriented person to use the system. As the user went through the tour, he was asked general questions like: “What do you think of this program?”, “Did you understand it?”, “Do you have questions about this tour?”, “Do you have any suggestions?”. The evaluation process helped identify problems that may be encountered by users of all skill levels as well as obtain constructive ideas for improvement (Xiao, D. Y. 2000).

The next section briefly describes the Emergent Themes Analysis (ETA) method that will be used in determining which of the two proposed usability evaluation methods: heuristic evaluation or think-aloud protocol is best for identifying usability problems in desktop, photo-realistic virtual environments and broad usability themes.
6.2.3 Emergent themes analysis

Emergent Themes Analysis (ETA) is “an iterative distillation process” developed by Wong and Blandford (2002) to help extract design insights by identifying themes and decision strategies from voluminous interview data from real-time operational environments (namely emergency ambulance dispatch). The ETA approach is based on Grounded Theory but tailored to take advantage of the exploratory and efficient data collection features of the Critical Decision Method (CDM), a retrospective interview technique requiring participants to recall a memorable incident that they have been involved in (Klein, G., Calderwood, R. et al. 1989), (Wong, B. L. W. 2004) when investigating the nature of decision making in the complex socio-technical domain of emergency ambulance dispatch (Wong, B. L. W. and Blandford, A. 2002). The following section will briefly describe Wong and Blandford’s analysis method in the context of the London Ambulance Service.

i. A CDM Interview Methodology was conducted to collect interview data from the participants. Participants were interviewed individually. They were asked to think back to a particularly memorable event they encountered in the course of their task. Participants actively participate in describing the incident, which helps construct a timeline of activities and aid in determining when critical decisions were made. All the interviews were audiotape recorded. Such a data collection method is rich in the data of the most demanding kind of incidents.

ii. CDM Data Analysis was then performed. The structured approach involves summarizing the incident, creating a timeline of the decision process in each incident and to show how each decision is progressively taken to action. Key decision points are then identified and charted. The decisions are further analyzed in a Decision Analysis table, which supports identification of cues, the mental processing, the outcomes, the reasons and overall goals. The cues, goals, mental processing and other interesting aspects are then consolidated across incidents. The process is illustrated in Figure 6-2 and the results presented in Figure 6-3.
Chapter 6: Research Techniques

Figure 6-2. CDM Decision Analysis Process – Incident Summaries are broken down to a timeline in a decision chart. Cues, goals, mental processing and other interesting aspects are categorized across incidents.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Cues, sources and considerations</th>
<th>Knowledge and experience</th>
<th>Difficulties, likely mistakes, consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Build a mental picture of the problem by integrating situation and incident information.</td>
<td>1. Information that describes the type of incident — call details screen.</td>
<td>1. &quot;Just doesn't look right&quot; or 6th sense — developed from experience and medical (on road) training. This knowledge is used to assess the situation</td>
<td>1. Uncertain information.</td>
</tr>
<tr>
<td>2. Collate information from many sources.</td>
<td>2. Information that describes the scene and the situation (e.g. for crew safety reasons) — could be in original call details screen or could be in another ticket.</td>
<td>2. Determining if calls are duplicates — flag calls with similar addresses rather than tie in on locations.</td>
<td></td>
</tr>
<tr>
<td>3. Corroborate evidence with others.</td>
<td>3. Information from police and fire — on separate tickets.</td>
<td>3. Flicking between summary and details screens to read, collate, compare and mentally integrate information — effortful process, highly memory intensive and therefore requires full attention.</td>
<td></td>
</tr>
<tr>
<td>4. Assess if the incident is real.</td>
<td>4. Call rate.</td>
<td>Summary display lacks visual discriminators or explanatory information.</td>
<td></td>
</tr>
<tr>
<td>5. Assess severity of incident (number of casualties).</td>
<td>5. Key cues expected - CHALET</td>
<td>4. Information from police and fire not differentiated on summary display.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-3. Data is further reduced by summarizing themes according to categories.

iii. The Emergent Themes Analysis (ETA) approach is applied as an iterative distillation process to reduce and to make sense of voluminous interview data such
as in a qualitative area such as a critical decision arena. Figure 6-4 outlines the key steps taken in an ETA approach.

Figure 6-4. Emergent Themes Analysis process

Broad themes are similar ideas and concepts reported across interviews and incidents. They are identified, indexed and collated. In this way, themes emerge from the interview data. In Wong and Blandford (2002), broad themes were initially associated with broad aspects of the decision process, such as the goals that an ambulance allocator needs to achieve. Using a similar distillation procedure, sub-themes, or specific themes within each broad grouping were identified, and the data and the specific themes are further categorized according to a framework for describing each decision process in finer detail. This framework has four categories that describe activities, cues, knowledge and difficulties of the processes, as illustrated in Figure 6-3. The specific themes and supporting data are then distilled into summary tables and narratives, which are descriptive prose that consolidated the data even further. The narratives and the summary tables are then interpreted, and relationships and new ideas about decision strategies are conceptualised. These decision strategies are again in narrative form, and written so as to provide understanding about the needs for representation.
6.3 Chapter Summary

This chapter presented an overview of research techniques relevant to this study. The purposes of this study is to first, determine whether results found in Koykka, et al. (1999) will be similar when applied in a desktop photo-realistic virtual environment, and second, to determine whether think-aloud protocol or usability heuristic evaluation is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual. In order to determine these, a heuristic evaluation, think-aloud protocol and a variation of the grounded theory approach called emergent themes analysis will be conducted and used for analysis, respectively.

The next chapter will detail the experimental methodology conducted in this research.
Chapter 7 Experimental Methodology

7.1 Introduction

This section documents the experimental methodology undertaken in this study. The objective of this experiment is to determine whether results found in Koykka, et al. (1999) will be similar when applied in a desktop photo-realistic virtual environment, a heuristic evaluation, think-aloud protocol, both qualitative research and usability evaluation methods will also be used.

The experimental methodology was conducted in two separate phases: think-aloud protocol and heuristic evaluations. Every single participant conducted both a think-aloud protocol and a heuristic evaluation. A brief overview of the two phases is presented in the next section.

Phase One: Evaluation of non-immersive, desktop, web-based photo-realistic VEs using think-aloud protocol

As detailed in Chapter 4 General Usability Evaluations and Chapter 6 Research Techniques, the participants performed a think-aloud protocol evaluation. This is when participants' voice their thoughts, opinions and comment on the system as they used it. In this study, thoughts, opinions and comments were captured using a digital video camera and on paper by the researcher for later reference.

Phase Two: Evaluation of non-immersive, desktop, web-based photo-realistic VEs using usability heuristics evaluation approach

In phase 2, a heuristics evaluation is an expert inspection method which helps find usability problems in a user interface design by allowing a small set of evaluators examine the interface. Evaluators' judge the user interface’s compliance to an established set of usability
principles. Jakob Nielsen’s ten usability heuristics were used in this experiment to evaluate the compliance of four photo-realistic virtual environments.

**Order of usability evaluation**

It is important to note that the order in which the evaluation was conducted is critical. A think-aloud protocol was performed before a heuristic evaluation. Performing the latter evaluation method first would affect the participant’s familiarity and learning of the system. For example, any initial difficulties with using interaction techniques such as navigation would have already been discovered through initial exploration and identification using the usability heuristics. This may result in the participant anticipating and compensating any difficulties when using the system during the think-aloud protocol. As this research is determining which evaluation method would identify a greater number of usability problems, initial issues may not be deemed important by the participant and therefore, will not be voiced out.

Below is a detailed account of the experimental process, in order to obtain valuable data relevant to each of the phases.

**7.2 Experimental Design**

The experimental design was a combined variation of a within and between subjects experiment. The ‘within subject’ aspect evolves from each participant evaluating two different but similarly scaled virtual environment systems such as the large scale web-based systems like the Sydney Opera House and the Questacon Science Center (see Appendix A: Virtual Environments), which presented an extensive number of nodes and navigational aids.

The experimental design enabled a ‘between subjects’ scenario as the usability problems identified between the different scales of the virtual environments will also be compared. Figure 7-1 briefly shows the between and within experimental design.
Chapter 7: Experimental Procedure

Figure 7-1. Between and within subject experimental design. Large and small VE systems will be compared within and between their respective categories.

7.2.1 The Virtual Environment (VE) systems
The virtual environment systems used in this experiment were from the World Wide Web (WWW). A basic set of criteria was applied in determining which system to choose. These are as follows:
- The virtual environment was web-based for easy accessibility,
- The virtual environment was photo-realistic and viewable in at least 180° angle.
- The VE systems had similar scale and complexities such as the number of location levels
- The VE system had similar number of nodes available within each system
- The VE system had similar presentation styles such as the use of interaction mechanisms such as navigational aids were similar.

Table 7-1 shows the four web-based VE systems, their complexities and presentation styles.

<table>
<thead>
<tr>
<th>Name and Location</th>
<th>Web address</th>
<th>Number of Floor Levels</th>
<th>Number of Nodes (Locations)</th>
<th>Interaction mechanisms present (Navigational Aids such as maps, embedded arrows, pop-up labels etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questacon Science Center</td>
<td><a href="http://virtual.questan.edu.au">http://virtual.questan.edu.au</a></td>
<td>5</td>
<td>approximately 40 nodes</td>
<td>3D map with links, embedded hotspots with hotspot indicators, orientation arrow on the 3D map, automatic VE rotation without mouse holding.</td>
</tr>
<tr>
<td>Wroxton Abbey</td>
<td><a href="http://www.wroxtonabbey.org/ind">http://www.wroxtonabbey.org/ind</a> ex1.html</td>
<td>1</td>
<td>approximately 7 nodes</td>
<td>2D map with links, embedded hotspots with labels on the control bar.</td>
</tr>
<tr>
<td>Richard Strauss' House</td>
<td><a href="http://www.richardstrauss.at/html">http://www.richardstrauss.at/html</a> _o/02_privat/0fs _index.html</td>
<td>1</td>
<td>approximately 7 nodes</td>
<td>3D map with links, embedded hotspots, with labels on the control bar.</td>
</tr>
</tbody>
</table>
Furthermore, Figures 7-2 to 7-5 shows screenshots of each starting node for the VE systems.

**Figure 7-2.** Starting node of VE System 1 - the Sydney Opera House (SydneyOperaHouse 2003).

**Figure 7-3.** Starting node of VE System 2 - the Questacon Science Center (Ma@dCommunications 2002).

**Figure 7-4.** Starting node of VE System 3 – the Wroxton Abbey (Goldbaum, H. 2003).


All systems allowed the use of interactive maps and embedded hotspots with which to navigate. All systems also presented additional information relevant to a user’s location in the VE system. The Sydney Opera House and Questacon Science Center had a similar number of nodes (40 or more locations). While Wroxton Abbey and Richard Strauss House had similar number of nodes (less than ten locations) (see Appendix A: Virtual Environments). Thus they formed natural groupings for the design study.
7.2.2 Ethical Approval

Prior to the commencement of the experiment, an ethical approval form was submitted to and approved by Professor George Benwell, Head of the Information Science Department, to undertake this experiment (see Appendix B: Ethical Approval).

7.2.3 Participants

Participants were students of the Information Science, University of Otago undergraduate course, INFO341 Human Computer Interaction. They were already familiar and knowledgeable in usability heuristic evaluations from previous class discussions. All participants were over the age of 18 years old and volunteered their time. There were twelve participants of varying age groups: seven were between 18-24, four were between 25-30 and one was between 31-40. There were seven males and five females. All participants were naïve in that they were not familiar with the use and location of the desktop photo-realistic panoramic virtual environments. Eight participants had played some type of three-dimensional (3D) games before, while four have not; two had experienced some form of virtual environment, while ten had not.

The next section details equipment used in the study.

7.2.4 Web Environment

All the web-based virtual environments were viewed using Microsoft Internet Explorer and Netscape Navigator web browser (version details available in each Equipment and Environment section of the different phases). The Internet Connection was through a local area network running on a 10baseT wire with 100Mbs connection.

7.3 Phase One: Evaluation of non-immersive, desktop, web-based photo-realistic VEs using think-aloud protocol

7.3.1 Equipment and Environment

7.3.1.1 Digital Video Cameras and Tripods for keystrokes, mouse movement and speech

Two Sony digital video cameras were mounted on a tripod each were used to collect the think-aloud protocol data such as the user’s keystrokes, screen mouse movement and speech. One camera was recording the participant’s keystrokes and mouse movements; while the other camera was recording the activities on screen as the participants used the VE system. Both cameras also recorded the participant’s voice as they voiced out their thoughts. Figure 7-6 shows how the equipment was set up.
7.3.1.2 Stop watch to gauge exploration and task completion times

A Lorus stopwatch was also used to gauge the time taken to explore the system and to complete the tasks. This data was recorded on a prepared spreadsheet along with their statistical details such as gender, age group etc. (see Appendix D: Data Collection Sheet).

7.3.1.3 Using the VE system equipment and environment for Phase One: Think-aloud protocol

A computer from the Information Science Department at the University of Otago was used in this experiment. The computer used was a Dell PIII 733 OptiPlex with 256Mb RAM machine with a standard keyboard, scrollable mouse and speakers. A Dell Liquid Crystal Display (LCD) screen was also used as the LCD’s faster screen refresh rates and no-to-low recordable “banding” was important in recording the user’s interaction on the screen compared to the traditional Cathode Ray Tube (CRT) screen. The participants also used Microsoft Internet Explorer version 6.026 and Apple QuickTime Player 6 software to view the VE system.

The experimental environment was selected to ensure the experiment could not be interrupted and could be undertaken in silence. The setting was selected to ensure distractions such as windows could not influence the results.

7.3.1.4 Task Sheets Design

Each system that was evaluated were assigned a list of tasks to be performed based on similar classifications of interactions within a VE system (Saretto, C. J. 1997).

However some definitions have been adjusted to fit a desktop, photo-realistic panoramic virtual environment. They are:
Chapter 7: Experimental Procedure

- Explore or browse – looking around the virtual environment to see what is available. It could also be used to orient oneself within the virtual environment, determine a viewer’s position e.g. north, south, east, west to help create a better mental model.
- Search – looking around the virtual environment with a specific target in mind. It could be for navigation or information such as objects and/or text, making a window (view) bigger, zoom in/out to find detail.
- Navigation/Travel – moving oneself around the virtual environment, deciding at each step where to go next based on the task and the parts of the environment seen so far.

In this experiment, an attempt to keep a constant number of tasks was made for each VE system class (see Appendix C: VE Tasks). For example, the Sydney Opera House and the Questacon Science Center, 14 tasks were set; whereas in the Wroxton Abbey and Richard Strauss House, there were 10 tasks set. All tasks within the four systems comprised of exploring, searching and navigation activities based on the above definitions. The tasks were designed to determine the basic usability of the system.

7.3.1.5 Participant Consent and Briefing

Each participant was first given an information sheet and a consent form to read and sign indicating their willingness to take part in the experiment and to signify that they understood the implications of participating (see Appendix B: Ethical Approval). Each participant was briefed before the experiment and asked to do the following:

- Answer statistical questions about themselves such as gender, age group, familiarity with the site, use of 3D games;
- familiarize themselves with a specific virtual tour for 15-30 minutes;
- perform a set of randomized tasks using the existing virtual tour, and;
- provide feedback about the application and the experimental procedures at the completion of the experiment.

7.3.2 Think-Aloud Protocol Procedure

The think-aloud protocol was conducted in five separate stages: an initial briefing, exploration, tasks performance, an interview and debriefing stage. Each participant conducted the TAP alone to avoid noise interference. Each one will be briefly described in the next section.

7.3.2.1 Initial Briefing

Each participant was initially briefed by being asked to read the information sheet and sign the consent form (section 7.3.1.5 above). To conclude the initial briefing, the researcher asked each participant if there were any questions that they would like to ask before the testing.
started such as further clarification of the procedures and expectations. Thereafter, statistical data such as age group, gender, proficiency in computer use (for example in 3D games) were requested from each participant and recorded on a prepared spreadsheet (see Appendix C: Data Collection Sheet).

7.3.2.2 Exploration Stage

Once completed, each participant was then asked to spend between 15-30 minutes to “familiarize themselves” with a randomly assigned VE system. The participants pulled a system name out of the hat. The familiarization process includes learning about techniques in using the system such as how pan within the VE, navigate between nodes or locations and select and manipulate objects. Concurrent to their exploration, participants were also asked two undertake additional activities:

- Do not consult the system help at all, and
- Speak out their thoughts (think-aloud), intentions, and actions in a clear and audible voice for recording purposes.

7.3.2.3 Task Performance Stage

When the participants felt comfortable using the system or after 30 minutes of familiarization or a list of tasks randomized at the researcher’s discretion was given to each participant. The tasks were randomized to prevent participants from detecting patterns of task behavior and thus anticipate actions that may affect the result. Each participant was asked to read the list of tasks before starting the next phase of the experiment so that they can plan their approach, if required. The participant was informed that each task was independent of each other, in that they may skip any task and then re-attempt the task later on in the experiment. Each participant was again asked to think-aloud as they endeavored to complete all the tasks. Time taken to complete the tasks was also recorded but this quantitative data was not used in the analysis as the research being conducted is of qualitative in nature. Therefore, qualitative data such as their thoughts and comments as they performed during this part of the investigation were of interest in this study.

During the exploration and the task completion process, if a participant was “too quiet” or was not ‘thinking aloud”, the researcher would prompt the participant by asking them some think-aloud questions (see Appendix E: Think-Aloud and Retrospective Questions).

7.3.2.4 Interview Stage

Upon completing the tasks, the researcher interviewed the participant by asking them a list of questions such as “what do you think of the [VE] system?” (see Appendix E: Think Aloud and Retrospective Questions). Answers and comments made during this session were also
Chapter 7: Experimental Procedure

recorded using the digital video camera and on paper by the researcher. The interview was necessary as it allowed the participants to think about what they have just done and re-enforce any difficulties that they encountered when using the system.

7.3.2.5 Debriefing Stage

At the completion of the experiment, each participant was debriefed, indicating that the next phase of the experiment was a heuristic evaluation, to be conducted at a separate time, thanked and dismissed. An example of users performing a think-aloud protocol is presented in Figure 7-7.

![Figure 7-7. Some examples of participants conducting a think-aloud protocol evaluation. The participant on the left was exploring the VE system. While the participant on the right was reading the tasks sheet.](image)

7.4 Phase Two: Evaluation of non-immersive, desktop, web-based photo-realistic VEs using usability heuristic evaluation

7.4.1 Equipment and Environment

The usability evaluators conducted heuristic evaluations using two different platforms: Macintosh and PC. Detailed machine and software specifications can be seen in Appendix F: Usability Heuristic Evaluation Equipment.

Each evaluator was provided with electronic versions of the Jakob Nielsen's Usability Heuristics (seen in Table 7-2) and Usability Heuristic Violation sheets for individual
evaluation and group collation in Microsoft 2000 Word and Excel format (see Microsoft 2000 Excel Individual Heuristic Violation example in Figure 7-8).

### Table 7-2. Nielsen’s (1994) Usability Heuristics

<table>
<thead>
<tr>
<th>Heuristic Name</th>
<th>Nielsen’s Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of system status</td>
<td>The system should always keep users informed about what is going on, through appropriate feedback within reasonable time - persistence.</td>
</tr>
<tr>
<td>Match between the system and the real world</td>
<td>The system should speak the users’ language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real world conventions, making information appear in a natural and logical order.</td>
</tr>
<tr>
<td>User control and freedom</td>
<td>Users often choose system functions by mistake and will need a clearly marked ‘emergency exit’ to leave unwanted state without having to go through an extended dialogue. Support undo and redo.</td>
</tr>
<tr>
<td>Consistency and Standards</td>
<td>Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.</td>
</tr>
<tr>
<td>Error Prevention</td>
<td>Even better than good error messages is careful design that prevents a problem from occurring in the first place.</td>
</tr>
<tr>
<td>Recognition rather than recall</td>
<td>Make objects, actions and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or retrievable whenever appropriate.</td>
</tr>
<tr>
<td>Flexibility and efficiency of use</td>
<td>Accelerators – unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater for both inexperienced and experience users. Allow users to tailor frequent actions.</td>
</tr>
<tr>
<td>Aesthetic and minimalist design</td>
<td>Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with relevant units of information and diminishes their relative visibility.</td>
</tr>
<tr>
<td>Help users recognize, diagnose and recover from errors</td>
<td>Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.</td>
</tr>
<tr>
<td>Help and documentation</td>
<td>Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user’s task, list concrete steps to be carried out, and not be too large.</td>
</tr>
</tbody>
</table>

Figure 7-8. An electronic Microsoft 2000 Excel file example that the evaluators used to record their individual usability heuristic evaluation.

#### 7.4.1.1 Heuristic Evaluation Procedure

As described in Chapter 3 and 5, in phase two, participants were asked to conduct a usability heuristic evaluation using Jakob Nielsen’s 1994 ten usability heuristics (see above). Each participant was assigned the ‘equivalent in scale’ VE system to evaluate. For example, if they conducted a think-aloud evaluation on the Sydney Opera House, then they would conduct a usability heuristic evaluation of the Questacon Science Center (see Table 7-1 above for similarities). The usability heuristics evaluation was conducted in three steps, approximately one week after the first participant performed the think aloud evaluation. This was to give all the participants the same base experience of conducting a type of VE evaluation before
starting on a usability heuristic evaluation. The participants conducted the usability heuristic evaluation in the following manner:

i. First, each individual participant “walked-through” their assigned system to get the ‘look-and-feel’ of using the system.

ii. Second, using Nielsen’s ten usability heuristics, each participant individually inspected the VE system for heuristic violations, give specific examples of where in the system the heuristic was violated and assign a severity rating for each violation.

Finally, participants who evaluated the same system would come together as a group and collate their individual heuristic evaluation results together. For each combination of identified example and heuristic violation, a tally was made of the number of times the violation has made (this is a frequency number). This violation is then group discussed to determine the criticality with which to address the problem based on the frequency number and the individual participant’s severity rating.

### 7.5 Chapter Summary

This chapter described the experimental resources and procedures used and performed in this study, respectively. The participants took part in two qualitative evaluation methods of four non-immersive desktop, photo-realistic virtual environments, namely a think-aloud protocol and usability heuristic evaluation. In order to determine whether results found in Koykka, M., Ollikainen, R., et al. (1999) will produce similar new heuristics for desktop virtual environments, and whether large-scale non-immersive, desktop, photo-realistic VEs will have more usability problems than small-scale VE systems, a variation of the grounded theory research method called Emergent Themes Analysis (ETA) will be used to analyze think-aloud protocol and usability heuristic violation data. This will also aid in determining whether think-aloud protocol or heuristic evaluation is the better method in identifying usability problems in desktop, photo-realistic virtual environments. The results and its discussion will be presented in Chapter 8.
Chapter 8  Experimental Results

This section will present results obtained from the experimental study. At the completion of each phase of the experiment, results from group heuristic evaluations were collected and think-aloud protocol and interview video recordings were transcribed. An Emergent Themes Analysis (ETA) approach was used to gain an understanding of what usability issues occurred when using a desktop, photo-realistic virtual environment. This “distillation process” was used to identify broad themes of usability problems in four web-based, desktop photo-realistic virtual environments. Usability problems like interactions styles in navigation, wayfinding, searching browsing, orientation, object selection and manipulation and system control will be identified as well as object and behavioral issues. The following section will briefly illustrate how the ETA approach will be used to identify broad themes from participants’ transcripts.

8.1 Data Analysis with Emergent Themes Analysis Approach

8.1.1 Procedure

i. Each individual participant transcripts is reviewed looking for user difficulties encountered when using the VE.

ii. Once reviewed, each transcript will be analyzed to identify common remarks made by the users. The following narratives below can be classified under the issue “Lack of Feedback” (where P## is the participant number and (0:00:00) is the time stamp).

P01 (0:06:53) - So when I press on it, suddenly the thing (popup text) comes up and sometimes it did not come up automatically and I have to wait a little while. So in the first place I'm trying to figure out what are these dots.

P02 (0:15:43) - Okay, actually to see this map. what does it (rolling over the 3D map) okay, I think this tell me about my position inside the house (rolling over the 3D map).
Chapter 8: Experimental Results

No, No, it's not my position. OK, What actually is in this position? I'm not sure where I can find my position here, I trying to find out.

P10 (0:59:23) - (Rolling over the different icons on the VR window). Umm, I'm wondering what is this thing (rolling over the link for high resolution panoramas), it's an icon for a real player. Click on it to see what it does (click on the QuickTime icon). Okay, it's loading an image, but I have to figure out how to use it now, just by possibly clicking (clicked on the image, no effect). Nothing is happening, and I'm wondering what I was supposed to do (0:59:59)...

P10 (0:51:34) - ...Um, and then I want to see one of these one, two, three (rolling over the Map Level links located on the bottom right hand side of the window screen). (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location label)...

P11 (0:01:18) - "And I'm not quite sure where I am (panning within the VR and as you pan, yellow arrows and 'i' for further information appears inside the VR indicating that it is click-able)."

P11 (0:08:53) - Okay, So going to the 1st level to the 3rd level and I don't know how I did that (panning within the VR, rolling over the embedded links)...

iii. Once all similar difficulties are gathered from individual participants, they are collated and re-analyzed across all the participants. Similar concepts are then collated. The collation below, illustrate how narratives are grouped together.

The response time for activating something is a little slow during which time there is nothing to indicate to the user what is happening (Feedback) in this case what its the yellow balls for a different location

P01 (0:06:53) - So when I press on it, suddenly the thing (popup text) comes up and sometimes it did not come up automatically and I have to wait a little while. So in the first place I'm trying to figure out what are these dots.

P10 (0:59:23) - (Rolling over the different icons on the VR window). Umm, I'm wondering what is this thing (rolling over the link for high resolution panoramas), it's an icon for a real player. Click on it to see what it does (click on the QuickTime icon). Okay, it's loading an image, but I have to figure out how to use it now, just by possibly clicking (clicked on the image, no effect). Nothing is happening, and I'm wondering what I was supposed to do (0:59:59)...

"How did I do that?"

P11 (0:08:53) - Okay, So going to the 1st level to the 3rd level and I don't know how I did that (panning within the VR, rolling over the embedded links)...

User is not sure of their current position/ location

P10 (0:51:34) - ...Um, and then I want to see one of these one, two, three (rolling over the Map Level links located on the bottom right hand side of the window screen). (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location label)...

P02 (0:15:43) - Okay, actually to see this map, what does it (rolling over the 3D map) okay, I think this tell me about my position inside the house (rolling over the 3D map). No, No, it's not my position. OK, What actually is in this position? I'm not sure where I can find my position here, I trying to find out.

P11 (0:01:18) - "And I'm not quite sure where I am (panning within the VR and as you pan, yellow arrows and 'i' for further information appears inside the VR indicating that it is click-able)."

iv. Following the above initial groupings, each collection of similar narratives is conceptualized into a problem. For example:
The user does not know what the VE system is doing. There is a lack of feedback to the user especially when loading.
The user does not know what they did to achieve the current system state
The user does not know their current position – spatial location, orientation
v. Finally, all the identified problems are then reviewed and analyzed for a common theme. In this case, the broad theme identified was "Lack of VE System Status Feedback."

Steps i-v are repeated again with the remaining data until there are no more broad themes that can be identified. Table 8-1 shows an example of how a broad theme can be developed from think-aloud protocol narratives and interviews.

Detailed examples of the ETA distillation process of the experimental data can be found in Appendix G: Emergent Themes Analysis of Heuristic Evaluation Results and Appendix H: Emergent Themes Analysis of Think-Aloud Protocols and Interviews CD.

8.1.2 Deciphering the results table

The results table is presented in columns. There are three main sections within the table. The broad theme and sub-themes column, the VE systems or its type and the "ticks" and "crosses".

Broad theme and sub-broad themes column contains derived broad themes of usability problems from the think-aloud protocol, heuristic evaluation and interviews. The researcher tried to make these themes as broad yet meaningful as possible.

VE system or its type columns refer to the specific VE systems evaluated or whether they were a small- or large-scale VE system.

"Ticks" and "Crosses" indicate whether that sub-broad theme was derived from data using one of the proposed evaluation methods. A "tick" means that is was "found" from the data and a "cross" means that it was not present in the data and therefore was not derived.
### Table 8-1. Deriving a broad theme for large-scale VE systems

<table>
<thead>
<tr>
<th>Narratives (Step 1-3)</th>
<th>Problem (Step 4)</th>
<th>Broad Theme (Step 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sydney Opera House: Deriving Sub-broad and Broad Themes from the Thinking-Aloud Protocol Evaluation Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P10 - Comments made were mainly about the web</td>
<td>P01</td>
<td>P02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P10 (0:51:34) - ...Um, and then I want to see one of these one, two, three (rolling over the Map Level links located on the bottom right hand side of the window screen). (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location label)...</td>
<td>P01</td>
<td>P02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.1.3 Results Presentation

The results are divided into three main sections. Section 1 will present issues from a within group analysis. This means think-aloud protocol results from evaluating similar scale virtual environments, namely, the Sydney Opera House versus the Questacon Science Center, (as an example of large-scale) and the Wroxton Abbey versus the Richard Strauss House (as an example of small-scale) will be presented. This is followed by results from the heuristic evaluations.

In section 2 think-aloud protocol and heuristic evaluations results from between groups will be presented. This section will compare results from the evaluations between large-scale VEs (Sydney Opera House and Questacon Science Center) versus small-scale VEs (Wroxton Abbey and the Richard Strauss House).

In section 3, a comparison of the think-aloud protocol with the heuristic evaluation within the same VE and between large- and small-scale VEs will be presented.

8.2 The Results

There were 4 broad themes derived using the Emergent Themes Analysis (ETA) approach. Each of the 4 broad themes was derived from sub-broad themes from the think-aloud protocol, interviews and heuristic evaluation data. The 4 broad themes are as follows:

1. Functionality - refers to the usefulness of or how well-designed were the VE systems.
2. Interaction - refers to the users' ability to invoke behavioral responses to objects within the VE. This may be within the entire VE itself or a specific area of the VE environment. This includes navigation and wayfinding, searching and browsing, object selection and manipulation and system control (Bowman, D. A., Johnson, D. B. et al. 1999; Stuart, R. 2001).
3. Appearance - Appearance refers to the aesthetic presentation of the VE system along with any related textual, numerical, image, sound or animated information. This includes whether the information presented was cohesive, easy to read and understand, and the quality of images were acceptable that the users were satisfied in using the system.
4. User Comments - refer to comments provided by the user at any point of the evaluation including the interviews. It is any comments, constructive or critical, made by the users with regards to the VE, its presentation, and suggestions for improvement that the researcher could not classify as usability problems within the functionality, interaction or appearance broad themes. User comments also refer to any experimental comments that the users made.
In the results, sub-broad themes will be presented and briefly described under the heading of one of the 4 broad themes derived.

8.2.1 Section 1: Within Groups

8.2.1.1 Think-Aloud Protocol Evaluation

Section 1 presents issues from a within group analysis. Results from a think-aloud protocol and interviews from evaluating similar scale virtual environments, namely, the Sydney Opera House versus the Questacon Science Center, and the Wroxton Abbey versus the Richard Strauss House will be presented. This is followed by results from the heuristic evaluations.

Table 8-2. Broad Themes identified from the Think-Aloud Protocol between the Sydney Opera House versus the Questacon Science Center and the Wroxton Abbey versus the Richard Strauss House.

<table>
<thead>
<tr>
<th>Broad Themes</th>
<th>Sydney Opera House</th>
<th>Questacon Science Center</th>
<th>Wroxton Abbey</th>
<th>Richard Strauss House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of VE system status feedback</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✔</td>
<td>✔</td>
<td>✔  ✔</td>
<td></td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✔</td>
<td>✔</td>
<td>✔  ✔</td>
<td></td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how rotate/pan within the VE</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to navigate such as travel from one location to another</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✔</td>
<td>✔</td>
<td>✔  ✔</td>
<td></td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✔  ✔  ✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✔</td>
<td>✔</td>
<td>✔  ✔</td>
<td></td>
</tr>
</tbody>
</table>

This section presents broad theme results from a think-aloud protocol and interview evaluation within the same scale VE system. This means that the Sydney Opera House was compared with the Questacon Science Center and the Wroxton Abbey was compared with the Richard Strauss House (indicated by the cell shading).

Table 8-2 presents broad themes and sub-themes identified within each system. As stated earlier, 4 broad themes were derived from the analysis of all sub-broad themes. The following sub-broad themes will be briefly described. They are as follows:

**Functionality**

Functionality refers to the usefulness of or how well-designed were the VE systems. Within each of the four VE systems, the following sub-broad themes were derived:
- the lack of VE system status feedback,
- hidden system functionality,
- hidden interaction system functionality, and
- limited freedom and movement

The lack of feedback was made obvious when users indicated that they did not know how they got to a particular location or a system state e.g. the user moved from the 3rd level of the VE system without knowing how they did that.

P11 (0:08:53) - Okay, So going to the 1st level to the 3rd level and I don’t know how I did that (panning within the VR, rolling over the embedded links)...

P02 (0:15:43) - Okay, actually to see this map, what does it (rolling over the 3D map) okay, I think this tell me about my position inside the house (rolling over the 3D map). No, No, it's not my position. OK, What actually is in this position? I'm not sure where I can find my position here, I trying to find out.

P08 (0:26:24) - Um, I wasn’t quite sure what that did (clicked on the hotspot of white spinning circle with the 4 orange triangles that brings up information about an object) in the first instance but I guess it’s just showing me what this angry arms thing is.

P03 (0:00:57) - ...I don’t know how to get to the fourth hotspot (moved over the map then VR, there’s no hotspot here (?)). Maybe if you zoom out (clicked on the zoom out button on the controller – no effect)...  

P09 (0:39:54) - ...And I got lost, I couldn’t remember what room I was in, at one, it comes up down in this bottom tool bar (QuickTime controller) where to go to. I thought it might have been a help to, I’m in the Chapel now, to have maybe – “You are currently in the Chapel”. So I ended up going right out of the building at one stage, couldn’t remember what room I was in.

P04 (1:22:04 - 1:22:57) - And show the hotspots (clicked on the “Show Hotspots” on the controller) so I can find my way outside. And that’s going into the Dining Room. The Library, go through the Dining Room, show the hotspots in here (clicked on the “Show Hotspots” on the controller), which is the Bay Window, or the Study, which I do not want to go back there. The Bay Window, which I think is 7? (labeled on the map). No. I thought I just went into the Bay Window but it’s telling me it’s the Hall. Um, Maybe I clicked on the wrong hotspot? But I can’t go back, can’t I?

Furthermore, comments from the TAP and interview transcripts about the user not knowing their current location within the VE and on the provided map suggests that the user has not effectively “linked” the different locations to their corresponding place on the map.

Therefore, the user has not achieved an accurate “mental map” of the VE. This may be due to the “superficial” exploration of the user when they first conducted the browsing wayfinding and navigation, which is an important exercise (Stanney, K. M., Mollaghasemi, M. et al. 2003).

P10 (0:51:34) - ...Um, and then I want to see one of these one, two, three (rolling over the Map Level links located on the bottom right hand side of the window screen). (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I’m wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location label)...

P11 (0:01:18) - ...And I’m not quite sure where I am (panning within the VR and as you pan, yellow arrows and “I” for further information appears inside the VR indicating that it is click-able).

P05 (0:20:40 - 0:21:07) - (clicked on the embedded spiral hotspot link to the Awesome Earth – Gallery 4), Um just thinking where I am (Rolling over the 3D orange balls on the 3D map, to bring up the location label). Yep. (started to pan within the VR). That I think I’m in the right place. (Clicked on the embedded spiral hotspot link to another part of the Awesome Earth Exhibit)
Furthermore, some of the functionalities were hidden to the user, like the ability to quickly and clearly exit an “unwanted state”. For example, some of the users were unsure how to return to their previous location or completely exit from the system.

Error correction/handling and robustness meaning that all computer systems should provide error correction and recovery before a permanent change is made (Kalawsky, R. S. 1999). This is one of the usability factors defined in the VRUSE questionnaire by Kalawsky. This is a similar situation with interaction object presented with the system being hard to find. For example interaction objects of the Windows environment such as scroll bars and close buttons as well as the VE controller buttons were not clearly visible.

**Interaction**

Interaction refers to the users’ ability to invoke behavioral responses to objects within the VE. This may be within the entire VE itself or a specific area of the VE environment. This includes navigation and wayfinding, searching and browsing, object selection and manipulation and system control (Stuart, R. 2001). Some of the interaction issues derived were:

- the limited usefulness of the navigational aids,
Chapter 8: Experimental Results

- the users requiring system exploration,
- the users searching for information and locations,
- some real world conventions that were not applicable in the VE system,
- the users having difficulty in determining how to rotate/pan within the VE environment, and
- how to navigate between nodes.

Users having difficulty in determining how to rotate/pan within the VE were issues in the Sydney Opera House, Wroxton Abbey and Richard Strauss House. This was not an issue within the Questacon Science Center as the Science Center provided navigational support in a form of a “post-it” at the system start-up level so that it is one of the first things that the user sees and reads. By the Questacon Science Center providing such a feedback and support mechanism at the system start up level, the users immediately knew how to pan and use the system, supporting one of (Koykka, M., Ollikainen, R. et al. 1999) heuristics, that of “3D environments should provide support for orientation, navigation and movement – providing feedback and support such as a start-up screen to explain the basic ways to move and use of functionalities would solve the inefficient way of accessing the different web services and content.” Some examples of the comments made include:

P01 (0:05:35) - Well, it’s kind of interesting to move around but it’s sometimes a bit hard to control ’coz it moves too fast.

P09 (0:08:34) - I’m pretty sure it will turn around here, and I’ll just try clicking to the right of the screen (clicked on the right of the screen – no effect), it doesn’t seem to help. I’ll try clicking on this hotspot arrow (Clicked on the “Show Hotspots” icon on the controller – does not see the hotspots). Ah, that’s not helping me much either. Um, there’s a little arrow here in the corner I’m might try, it didn’t do anything either (Back button on the controller)

P04 (1:02:04) - ...I can’t turn around and I want to see the rest of the room.

P07 (0:20:15 - 0:20:25) - I don’t know that it’s that’s, that’s hard because, the only way would be really to give the users some understanding of how to move...From side to side, so um, I don’t know, the whole dot is a pretty meaningless thing (cursor change). I mean even when you click it, which is what I did to start with, I just clicked it, just to see whether it changed...And um, that doesn’t change at all so you think the dot, is just a dot literally it’s just a pointer. Whereas perhaps, if, when you clicked on that dot, it changed to arrows...So then it gave you some idea that when you’re holding it down then you could actually move. Umm, yeah.

Users having difficulty determining how to navigate from one location was identified as another usability theme between the Wroxton Abbey and the Richard Strauss House but not within the Sydney Opera House and the Questacon Science Center. This is due to the related issue that the user did not know how to pan around the system.

P01 (0:07:55) - Well, it would be nice to actually guide, to give them, like if they are going to tour around, guide them from one site, like let them walk from the west onwards (clicked on the yellow ball map link), look around here west and then move around all the way down west. Like how people do walks. Instead of like I have to find here then the next moment I have to be at the other site, the south, it’s confusing.

P11 (0:15:57) - So it moved further than I thought it would (panning within the VR, rolling over the embedded links, clicked on an embedded hotspot leading to the Opera Theater Foyer East, rolling over the embedded links) Try this one (clicked on an embedded hotspot leading back to the Opera Theater Foyer South).
P05 (0:29:23) - And like, it's a bit hard to navigate around. Like on the actual, like when I went up the ramp and stuff. And I was getting a bit lost though, because there wasn't anything telling me where I could go. Like maybe, no signs or anything. And, um, yeah, that was a bit annoying.

P09 (0:09:49) - Um, and that's stuck, don't know what to do, just try zooming in and out (Zoom in using the plus button on the controller, zoom out using the minus button on the controller).

P07 (0:18:21) - at first, I didn't know how to navigate, the map was good to get around, so that other people would probably be in the same situation, so it's good to actually be able to move around, even if you don't know that you can. Do a full turn, um

Navigating within the Wroxton Abbey and the Richard Strauss House is mainly done using embedded hotspots within the VE system. If the user does not know how to pan around the system, the user will not be able to roll over the hotspot. This also the case if users activated the “show hotspot icon” on the controller – without knowing how to pan around, the user will not even see the link, therefore, will not be able to move to a different location.

Appearance

Appearance refers to the aesthetic presentation of the VE system along with any related textual, numerical, image, sound or animated information. This includes whether the information presented was cohesive, easy to read and understand, and the quality of images were acceptable that the users were satisfied in using the system. Some of derived issues include:

- information presentation such as the amount of text presented with the VE system,

  P03 (0:38:07 - 0:39:14) - (Navigation) I found it very good, actually. Uhm, Things were there for a purpose. To harness exploration. At the same time, uhm, I get a little bit distracted about with the pictures and I see a lot of things on the right hand side, Like Historical facts and years. I'm interested in history but at the same time where you have text in here, it just seems, that I could end up not reading the text and look at something more interesting part. Why should I read the text when I could watch the movie for half an hour or something. It's something that interests you. This is more like Lords and specs to me. "Pope...William Pope and Sir Thomas blah, blah, blah", Became a knight here. It's not telling a story. It's more like who owned this house, who hanged around here. It doesn't make sense to me...

  P07 (0:03:27) - Just reading the text again (Scrolling down the text). Skimming the text, because this time there's a lot ...

- the use of jargon, icons, symbols etc and

  P10 (0:54:00) - What is this "i" thing? (Panning within the VR and as you pan, yellow arrows and "i" for further Information appears inside the VR that this clickable). Can I, like, it's not a help thing? So I can just click on it?

  P01 (0:01:05) - Preston bar... Not really sure what is it. I'm moving out to see if I could find it somewhere else.

  P02 (0:11:20) - Yeah, I'm over the bridge now and I can see around (pan), what's around the place, and there is a small "O" I think to take me to a different place that I would like to see. For example, I'll click on this arrow (clicked on the embedded hotspot). There, this number explains it.

  P05 (0:32:57) - ...Like "QuickTime VRS", it's like "what does VRS stand for?"
Chapter 8: Experimental Results

P08 (1:11:50) - Let me go to the Plant Room here (clicked on the red 3D map that links to the Plant Room). Ooh, I thought that it might have had plants up there.

P09 (0:29:25) - "Name the date that Augustinian Priory Foundation was constructed".
I don't really know what that is.

P04 (0:59:47) - ...And that means that I'm here on the map (Dining room) so I go next door, whatever "7" is (clicked on the map link). The Bay Window, no, the Façade...

P06 (0:44:42) - Up there (top left hand corner of the window, where the icon of Garmisch is), ah, what does that do up there? Nothing, no, was just actually seeing if there was any other, I've noticed those two down there...

- the poor quality of the VE images that deterred the users from completing some of the searching tasks or to further explore the objects in closer view.

P02 (0:55:45 - 0:57:16) - ...It's not clear the seat numbers. How can I find it?
(Checked on an embedded hotspot, panning). I'm just tring to find (clicked on the "I" embedded within the VR in the Royal Box U, which displayed a text box). Hmmm
(scanning the text again, closed the text box, panning the panorama). I don't think It's clear to me where to find (clicked on an embedded hotspot, panning) this is the last time...I don't know. I don't think this is what they want (clicked the close window for the text box). They want the number of the seats but I can't, I don't know how I can find the numbers of the seats. So (clicked on the embedded hotspot, panning). So they want the number that actually appear on here (pointing at the individual seats themselves)?

P11 (0:22:37 - 0:23:51) - (Rolled over some embedded hotspots, clicked on an embedded hotspot leading to Concert Hall Foyer East) see if going here can get me closer to them (colored boxes, panning within the VR) it doesn't. (Rolled over some embedded hotspots, clicked on an embedded hotspot leading to Concert Hall Foyer South, panning within the VR) Uhmm, I don't know how to read the labels on them (0:22:53). (Rolled over some embedded hotspots, guessing what the boxes would say) I think one (yellow arrow) must point west, one east and maybe one down? I don't know. Is that okay? (In fact the colored boxes say "Doors 1-7 <", "Coffee Bar ", Doors 8-12 >". (Reading the task sheet – Task 4b, right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom in) I suppose clicking in the zoom in, makes it closer. Is that what’s meant by making it bigger?

P03 (0:31:02) - To me it looks like "4,6"- nine light bulbs which consists of two layers of and candles, and six below and three on the next one. It's a little bit hard to see from this angle.

P12 (0:56:20 - 0:56:39) - ...Is that a flag rolled up or something?...I'm not sure that's what it is. It's a blue flag.

These issues were derived from the Sydney Opera House, Wroxton Abbey and Richard Strauss House. However, the poor image quality of the VE was not an issue for the Questacon Science Center.

User Comments

User comments refer to comments provided by the user at any point of the evaluation. It is any comments, constructive or critical, made by the users with regards to the VE, its presentation, and suggestions for improvement that the researcher could not classify as usability problems within the functionality, interaction or appearance broad themes. User comments also refer to any experimental comments that the users made. In all four systems, users commented on the VE presentation and made suggestions like the VE and the map combination was good and that perhaps the Wroxton Abbey VE window and the map could be at the same eye level.
Chapter 8: Experimental Results

P03 (0:15:27 - 0:18:49) - And maybe I would like to have this map on the right hand side a little bit at the same level as the scroll window. It would be nice to have it the same level as the picture (VR). Okay... Why? Because all of the hotspot would be visible 'coz the hotspot number 1 is covered, can't see the whole map on the map, you can't see the whole map and it will decrease visibility (moved the scrollbar up and down) and ease the navigation.

P09 (0:44:08 - 0:44:18) - This map (pointing to the 1D map), it wasn't really like ah, find that, there's another screen apart from this one, it's sort of half cut off. I though maybe, umm, if the screen could be arranged better. Maybe the map in one of the corners, up the top so it's always visible instead of having to scroll down to find it. But, umm, yeah apart, I think if I had of grasped the instructions a little easier, figured out at the start, once you know how to do it, it's pretty easy to find your way around.

P02 (0:53:26 - 0:53:50) - (reading the task sheet) "Name the visiting Royal who sat there in listening to Beethoven's Symphony No 9 in D minor". Okay, this is getting more difficult. So I'm not sure what I'm looking for now... (panning). I don't know how can I get his name from here.

P11 (0:23:51) - (Reading the task sheet – Task 4b, right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom in) I suppose clicking in the zoom in, makes it closer. Is that what's meant by making it bigger?

P05 (0:36:55 - 0:37:24) - Um, (0:37:00) Actually just, (rolling over the 3d orange balls on the 3D map to bring up location labels), um, you had "Front Entrance" or something over here. I just assumed that the Front Entrance was the Patio 'coz I think it says, it's different 'coz I think because this is called the Foyer, and this is the Patio. So I wasn't sure if the Patio is the Front Entrance.

The most common experimental comment made was that of the ambiguous wording of the task sheet questions.

Table 8-2 presented broad themes derived from the think-aloud protocol of same size-scaled VEs. The broad themes provided issues of functionality, interaction, appearance and user comments. The sub-broad theme of users having difficulty determining how to navigate from one location to another, users having difficulty in determining how to rotate/pan within the VE (Interaction) and the poor VE image quality were all issues derived from the TAP data except for the Questacon Science Center.
The next table will present heuristically evaluated derived theme results from a within same size-scale VE analysis.

### 8.2.1.2 Heuristic Evaluation

**Table 8-3.** Broad Themes identified from the Heuristic Evaluation of the Sydney Opera House versus the Questacon Science Center and the Wroxton Abbey versus the Richard Strauss House.

<table>
<thead>
<tr>
<th>Broad Themes</th>
<th>Sydney Opera House</th>
<th>Questacon Science Center</th>
<th>Wroxton Abbey</th>
<th>Richard Strauss House</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of VE system state feedback</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden System Functionality - there is no quick UNDO of actions available to the user, to poor use of the metaphor</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Functions of interaction objects are hidden from the user</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited system help and documentation</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lack of cross-platform availability</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>A clear distinction of functionalities between novice and experienced users is needed.</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult for user's to know their current location</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Navigational Aid - the map options are hidden from the user</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Difficult to know what options are available such as locations to view without exploration</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR Presentation needs to be improved.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Location and size of hotspots</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>×</td>
</tr>
</tbody>
</table>

This section presents broad theme results from a heuristic evaluation within the same scale VE system. The broad themes from the heuristic evaluations were derived from usability problem descriptions from the evaluators (see data in Appendix F: Emergent Themes Analysis of Heuristic Evaluation Results).

Table 8-3 presents broad themes and sub-themes identified within each system. As stated earlier, 3 broad themes were derived from the analysis of all sub-broad themes. The following sub-broad themes will be briefly described. They are as follows:

**Sydney Opera House vs. Questacon Science Center (Large-scale VE systems)**

**Functionality**

The functionality sub-broad themes that were derived from the heuristic evaluation of the Sydney Opera House and the Questacon Science Center included limited or lack of VE system state feedback, hidden system and interaction objects functionality.
Limited or lack of VE system state feedback and hidden system were derived from the
Sydney Opera House but not in the Questacon Science Center. Conversely, hidden
functionality of the interaction objects were derived from the Questacon Science Center but
not in the Sydney Opera House.

**Interaction**

With regards to the interaction sub-broad themes, users had difficulty determining their
current location, as well as user required further exploration to determine what options and
locations are available, lack of a cohesive link between the navigational aid such as the map
and the VE, real world conventions expected to be present within the VE system but was
absent by the user, hidden navigational aid, limited Field of View (FoV) or “user head”
movement were derived. Both the systems found that a link between the navigational aid such
as the map and the VE is lacking due to the navigational aids like the map being hidden from
the user. However, the hidden navigational aid and real world conventions expected to be
present within the VE system but was absent by the user, were derived from the Questacon
Science Center but not from the Sydney Opera House. Furthermore, limited Field of View
(FoV) or “user head” movement, the users need to explore the system in order to find out
what is available were derived from the Sydney Opera House but not in the Questacon
Science Center.

**Appearance**

Within the appearance broad theme, the need for improvement in terms of the VR
presentation was derived from both the Sydney Opera House and the Questacon Science
Center.

**Wroxton Abbey vs. Richard Strauss House (Small-scale VE systems)**

**Functionality**

The functionality sub-broad themes that were derived from the heuristic evaluation of the
Wroxton Abbey and the Richard Strauss House included limited or lack of VE system state
feedback, hidden system and interaction objects functionality, limited availability of system
help and documentation as well as the lack of cross-platform availability and distinct novice
and expert functionalities.

Limited or lack of VE system state feedback was derived and hidden functionality of
interaction objects from both the Wroxton Abbey and the Richard Strauss. While hidden
system functionality, limited availability of system help and documentation and the lack of
distinct novice and expert functionalities were derived from the Wroxton Abbey but not from
the Richard Strauss House. However, the lack of cross-platform availability was derived from
the Richard Strauss House but not from the Wroxton Abbey.
Chapter 8: Experimental Results

Interaction
With regards to the interaction sub-broad themes, real world conventions expected by the user to be present within the VE system but was not was derived from the Wroxton Abbey but not from the Richard Strauss House. Furthermore, limited Field of View (FoV) or “user head” movement was derived from both the Wroxton Abbey and the Richard Strauss House.

Appearance
Within the appearance broad theme, the need for improvement in terms of the VR presentation and location and size of the hotspots were derived from the Wroxton Abbey but not from the Richard Strauss House. Conversely, need for improved information presentation of relevant information was derived from the Richards Strauss House but not from the Wroxton Abbey.

8.2.1.3 Summary
Table 8-2 presented broad themes derived from the think-aloud protocol of same size-scaled VEs. The broad themes provided issues of functionality, interaction, appearance and user comments. The sub-broad themes like users having difficulty determining how to navigate from one location to another, or how to rotate/pan within the VE (Interaction) and the poor VE image quality (Appearance) were all issues derived from the TAP data except for the Questacon Science Center.

Table 8-3 presented broad themes derived from a heuristic evaluation of the same size-scale VEs. In terms of the Sydney Opera House versus the Questacon Science Center, functionality broad themes include limited or lack of VE system state feedback and hidden system sub-broad themes were derived from the Sydney Opera House but not in the Questacon Science Center. Conversely, hidden functionality of the interaction objects were derived from the Questacon Science Center but not in the Sydney Opera House were all derived.

With regards to the interaction sub-broad themes, users had difficulty determining their current location, as well as user required further exploration to determine what options and locations are available, lack of a cohesive link between the navigational aid such as the map and the VE, real world conventions expected to be present within the VE system but was absent by the user, hidden navigational aid, limited Field of View (FoV) or “user head” movement were derived.

Within the appearance broad theme of the Sydney Opera House versus the Questacon Science Center, the need for improvement in terms of the VR presentation was derived from both the large-scale systems.
In terms of the Wroxton Abbey and Richard Strauss House, functionality sub-broad themes that were derived from the heuristic evaluation of the small-scale VE system included limited or lack of VE system state feedback and hidden functionality of interaction objects derived from both the Wroxton Abbey and the Richard Strauss. While hidden system functionality, limited availability of system help and documentation and the lack of distinct novice and expert functionalities were also derived from the Wroxton Abbey but not from the Richard Strauss House. Finally, the lack of cross-platform availability was derived from the Richard Strauss House but not from the Wroxton Abbey.

Common broad themes will be described in Chapter 9: Discussion.

Section 2 will present derived broad and sub-broad theme results from a think-aloud protocol and heuristic evaluation of a between size-scale VE analysis: large versus small-scale VE systems.
8.2.2 Section 2: Between Groups

8.2.2.1 Think-Aloud Protocol Evaluation

Section 2 presents a think-aloud protocol, interview and heuristic evaluations results from between groups. This section will compare results from the evaluations between large-scale VEs (Sydney Opera House and Questacon Science Center) versus small-scale VEs (Wroxton Abbey and the Richard Strauss House).

Table 8-4. Broad Themes found from the Think-Aloud Protocol of Large VE Systems (Sydney Opera House and the Questacon Science Center) versus the Small VE Systems (Wroxton Abbey and the Richard Strauss’ House).

<table>
<thead>
<tr>
<th>Broad Themes</th>
<th>Large VE Systems</th>
<th>Small VE Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of VE system status feedback</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how rotate/pan within the VE</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to navigate such as travel from one location to another</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>User Comments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 8-4 presents a comparison of the large-versus the small-scale VE system using the think-aloud protocol and interview method.

**Functionality**

Within the heuristic evaluation, limited or lack of VE system status feedback, hidden system and interaction object functionality and limited freedom and movement were identified both within the large- and small-scale VE system under the Functionality broad theme.

**Interaction**

In terms of the interaction broad theme, limited usefulness of the navigational aids, users requiring system exploration and information and location searches and real world conventions were not applicable in the VE system were found in both the large-scale and small-scale VE. While users’ experiencing difficulty in determining how to pan within the VE as well as navigate from one location to another was derived in the large-scale VE but not in the small-scale VE. This is perhaps due to the large amount of nodes that the user can visit and the many links that exists between each of the many nodes.

**Appearance**

94
Within the appearance broad theme, the need to improve the VE presentation was derived within the TAP evaluation. The need to improve the VE image quality was derived in the small-scale VE systems.

**User Comments**
Comments about the VE presentation and suggestions for its improvements were derived from both the TAP and HE evaluations. Furthermore, experimental comments were also made in both the TAP and the HE evaluation.

Broad and sub-broad themes from the Heuristic Evaluation of large- versus small-scale VE Systems will be presented next.

### 8.2.2.2 Heuristic Evaluation

**Table 8-5.** Broad Themes found from the Heuristic Evaluation of Large VE Systems (Sydney Opera House and the Questacon Science Center) versus Small VE Systems (Wroxton Abbey and the Richard Strauss’ House).

<table>
<thead>
<tr>
<th>Broad Themes</th>
<th>Large VE Systems</th>
<th>Small VE Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of system state feedback</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Functions of interaction objects are hidden from the user</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult for user’s to know their current location</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR Presentation needs to be improved.</td>
<td>✓</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 8.5 presents a comparison of the large-versus the small-scale VE system using the heuristic evaluation method.

**Functionality**
Within the heuristic evaluation, limited or lack of VE system status feedback, and hidden interaction object functionality were identified within the small-scale VE system under the Functionality broad theme but not in the large-scale VE.

**Interaction**
In terms of the interaction broad theme, users difficulty in determining their current location was found in the large-scale but not in the small-scale VE. A complete and clear relationship between the navigational aid (map) and the VR is missing and the users’ limited field of view was derived in the large-scale VE but not in the small-scale VE.

**Appearance**
Within the appearance broad theme, the need to improve the VE presentation was derived within the TAP evaluation.
8.2.2.3 Summary

Table 8-4 presented the broad themes from a think-aloud protocol and interviews analysis between different size-scale VE systems. The results are similar to Section 8.2.1: Within Group Analysis with the exception of the users' having difficulty determining how to pan within the VE and navigate between one node to another and the need to improve the image quality of the photo-realistic VE. This issue was not derived in the large-scale VE system.

Table 8-5, however, presented a more interestingly diverse result. Functionality sub-broad themes like limited or lack of system state feedback and hidden interaction objects functionality were derived in only small-scale VEs. Interaction broad themes, such users difficulty determining their current location was found in the large-scale but not in the small-scale VE. A complete and clear relationship between the navigational aid (map) and the VR is missing and the users' limited field of view was derived in the large-scale VE but not in the small-scale VE. The need to improve the VE presentation was derived within the TAP evaluation (Appearance). It is also interesting to note that the heuristic evaluation identified a greater number of functional and interaction sub-broad themes issue in the small-scale VE systems than in the large-scale. This finding is contrary to the hypothesis that large-scale VE systems should present more usability problems than small-scale VE systems.

Section 3 will present results from a methodology comparison of the think-aloud protocol and heuristic evaluation methods within each and across all VE systems.
8.2.3 Section 3: Think-Aloud Protocol versus Heuristic Evaluations

8.2.3.1 Sydney Opera House

Section 3 presents a comparison of the think-aloud protocol with the heuristic evaluation within the same VE system.

Table 8-6. Think-Aloud Protocol versus Heuristic Evaluation for Sydney Opera House.

<table>
<thead>
<tr>
<th>Sydney Opera House Broad Themes</th>
<th>Think Aloud Protocol</th>
<th>Heuristic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited or lack of VE system status feedback</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how rotate/pan within the VE</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Difficult for user's to know their current location</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR Presentation needs to be improved.</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Location and size of hotspots</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>User Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✓</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 8-6 presents a comparison of the think-aloud protocol and heuristic evaluation results of the Sydney Opera House VE system.

Functionality

Within the Sydney Opera House evaluation, limited or lack of VE system status feedback, and hidden system and interaction object functionality and limited freedom and movement were identified under the Functionality broad theme. The TAP and HE evaluation both identified hidden system functionality within the VE system, limited or lack of VE system feedback. While the TAP method identified hidden interaction object functionality and limited freedom and movement but not in the HE evaluation.

Interaction

In terms of the interaction broad theme, users requiring system exploration was an issue common between the TAP and the HE. While real world conventions were not applicable in the VE system, limited usefulness of the navigational aids and information and location searches were derived within the TAP data but not in the HE. Users having difficulty determining their current location and having limited field of view movement were identified in the HE but not in the TAP.

Appearance
Within the appearance broad theme, the need to improve the VE presentation was derived from HE evaluation. While the need to improve information presentation, the quality of the VE images as well as the location and size of the hotspots were derived from the TAP method but not in the HE.

**User Comments**
Comments about the VE and suggestions for its improvements were made during the TAP evaluation but not identified in the HE. Furthermore, experimental comments were also made in the TAP but not identified in the HE.

### 8.2.3.2 Questacon Science Center

Table 8-7. Think-Aloud Protocol versus Heuristic Evaluation for Questacon Science Center.

<table>
<thead>
<tr>
<th>Questacon Science Center Broad Themes</th>
<th>Think Aloud Protocol</th>
<th>Heuristic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Lack of VE system status feedback</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Interaction</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Difficult for user's to know their current location</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>User Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
</tbody>
</table>

Table 8-7 presents a comparison of the think-aloud protocol and heuristic evaluation results of the Questacon Science Center VE system.

**Functionality**
Within the Richard Strauss House evaluation, limited or lack of VE system status feedback, and hidden system and interaction object functionality and limited freedom and movement were identified under the Functionality broad theme. The TAP and HE evaluation both identified hidden interaction object functionality. While the TAP method identified limited freedom and movement within the VE system, limited or a lack of VE system feedback and hidden system functionality.

**Interaction**
In terms of the interaction broad theme, real world conventions were not applicable in the VE system and limited usefulness of the navigational aids were issues common between the TAP and the HE. Users requiring system exploration and information and location searches were derived from the TAP data but not in the HE. User difficulty determining their location was identified in the HE but not in the TAP.
Chapter 8: Experimental Results

**Appearance**
Within the appearance broad theme, the way information was presented was derived from both TAP and HE evaluation. This is perhaps due to specific searching tasks that were assigned to the users in the TAP but not in the HE.

**User Comments**
Comments about the VE and suggestions for its improvements were made during the TAP evaluation but not identified in the HE. Furthermore, experimental comments were also made in the TAP but not identified in the HE.

### 8.2.3.3 Wroxton Abbey

Table 8-8. Think-Aloud Protocol versus Heuristic Evaluation for Wroxton Abbey.

<table>
<thead>
<tr>
<th>Wroxton Abbey Broad Themes</th>
<th>Think Aloud Protocol</th>
<th>Heuristic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of VE system status feedback</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Limited system help and documentation</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>A clear distinction of functionalities between novice and experienced users is needed</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to rotate/pan within the VE</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to navigate such as travel from one location to another</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Location and size of hotspots</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>VR Presentation needs to be improved.</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td><strong>User Comments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✓</td>
<td>x</td>
</tr>
</tbody>
</table>

Table 8-8 presents a comparison of the think-aloud protocol and heuristic evaluation results of the Wroxton Abbey VE system.

**Functionality**
Within the Richard Strauss House evaluation, limited or lack of VE system status feedback, hidden system and interaction object functionality, limited freedom and movement within the VE system including help and documentation as well as a clear functionality distinction between the novice and the user were identified under the Functionality broad theme. The TAP and HE evaluation both identified limited or lack of VE system status feedback and hidden system and interaction object functionality. The TAP identified limited freedom and movement within the VE system, whilst the HE found limited help and documentation and a
clear functionality distinction between the novice and the user within the VE system as their sub-broad themes.

**Interaction**

In terms of the interaction broad theme, real world conventions were not applicable in the VE system was an issue common between the TAP and the HE. Conversely, limited usefulness of the navigational aids, users requiring system exploration, users needed to search for information and locations, as well as users expressed difficulty in trying to figure out how to rotate/pan within the VE and navigate from one location to another was only identified in the TAP but not in the HE. While, limited FoV movement was only derived in the HE but not in the TAP.

**Appearance**

Within the appearance broad theme, the way information was presented and the need to improve the image quality of the VE were only derived from the TAP but not during the HE. This is perhaps due to specific searching tasks were assigned to the users in the TAP but not in the HE. Conversely, the location and size of hotspots and the way the VR presentation needed to be improved was only derived in the HE but not in the TAP for the Wroxton Abbey. This was perhaps due to a related issue of the instructions presented about how to navigate and travel within the VE was ambiguous, which caused the user not to immediately locate the hotspots and thus, frustration to the user.

**User Comments**

Comments about the VE and suggestions for its improvements were made during the TAP evaluation but not identified in the HE. Furthermore, experimental comments were also made in the TAP but not identified in the HE.
8.2.3.4 Richard Strauss House


<table>
<thead>
<tr>
<th>Richard Strauss House Broad Themes</th>
<th>Think Aloud Protocol</th>
<th>Heuristic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of VE system status feedback</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Lack of cross-platform availability</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how rotate/pan within the VE</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to navigate such as travel from one location to another</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td><strong>User Comments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VE presentation comments and suggestions for improvement</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Experimental Comments</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 8-9 presents a comparison of the think-aloud protocol and heuristic evaluation results of the Richard Strauss VE system.

**Functionality**

Within the Richard Strauss House evaluation, limited or lack of VE system status feedback, hidden system and interaction object functionality, limited freedom and movement within the VE system and the lack of cross-platform availability were identified under the Functionality broad theme. The TAP and HE evaluation both identified limited or lack of VE system status feedback and hidden interaction object functionality. The TAP identified lack of cross-platform availability, whilst the HE found hidden system functionality and limited freedom and movement within the VE system as their sub-broad themes.

**Interaction**

In terms of the interaction broad theme, limited usefulness of the navigational aids, users requiring system exploration, users searches for information and locations, real world conventions were not applicable in the VE system, users had difficulty trying to figure out how rotate/pan within the VE and how to navigate such as travel from one location to another was only an issue in the TAP but not in the HE. Conversely, a complete and clear relationship between the navigational aid (map) and the VR is missing and limited FoV movement was only identified in the HE and not in the TAP.
Appearance
Within the appearance broad theme, the way information was presented was found by both the TAP and the HE evaluation. While, the need to improve the image quality of the VE was only an issue identified in the TAP but not during the HE. This is perhaps due to specific searching tasks were assigned to the users in the TAP but not in the HE.

User Comments
Comments about the VE and suggestions for its improvements were made during the TAP evaluation but not identified in the HE. Furthermore, experimental comments were also made in the TAP but not identified in the HE.
### Table 8-10. Comparing Think-Aloud Protocol versus the Heuristic Evaluation across all systems.

<table>
<thead>
<tr>
<th>Broad Themes</th>
<th>Sydney Opera House</th>
<th>Questacon Science Center</th>
<th>Richard Strauss</th>
<th>Wroxton Abbey</th>
<th>Sydney Opera House</th>
<th>Questacon Science Center</th>
<th>Wroxton Abbey</th>
<th>Richard Strauss</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited or lack of VE system status feedback</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden system functionality</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hidden functionality of interaction object presented with the system</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited freedom and movement within the system</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lack of cross-platform availability</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>A clear distinction of functionalities between novice and experienced users is needed.</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>A clear distinction of functionalities between novice and experienced users is needed.</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited usefulness of the navigational aids</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users requiring system exploration</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users searches for information and locations</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Real world conventions were not applicable in the VE system</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how rotate/pan within the VE</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Users had difficulty trying to figure out how to navigate such as travel from one location to another</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Limited FoV movement</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Difficult for users to know their current location</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information presentation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>The VE image quality needs improvement</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>VR Presentation needs to be improved</td>
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<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td><strong>User Comments</strong></td>
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<td></td>
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<tr>
<td>VE presentation comments and suggestions for improvement</td>
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<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>
Table 8-10 presents a comparison between the think-aloud protocol and the heuristic evaluation across all systems. The results suggest that evaluation using the think-aloud protocol derived more sub-broad themes compared to the heuristic evaluation.

### 8.2.3.5 Summary

Tables 8-6 to 8-9 presented results comparing the think-aloud protocol against heuristic evaluation within the same VE and between large- and small-scale VEs. Table 8-10 presented a comparison between the think-aloud protocol and the heuristic evaluation across all systems. From an inspection analysis of the broad themes within each of the VE systems, a greater number of sub-broad themes were derived under the functionality, interaction and appearance and user comments broad themes. Another interesting finding is that think-aloud protocol derived more sub-broad themes compared to the heuristic evaluation within-between- and across systems. Three of the four case studies (not Wroxton Abbey) of think-aloud protocol outperformed the performed the heuristic evaluation especially with regards to identifying Interaction broad themes.

### 8.3 Chapter Summary

There were some interesting results derived from this study. They are as follows:

Four broad themes of functionality, interactions, appearance and user comments were identified in section 8.2.1. Within each of these broad themes, a multitude of sub-broad themes that relate to issues within the photo-realistic virtual environments were found within the four evaluated web-based VE systems. These will be compared against Koykka et al.’s additional 3D usability design categories.

Between the large- and small-scale VE systems comparison, a greater number of functionality, interaction and appearance problems were derived in the small-scale VEs using the heuristic evaluation method.

Overall, think-aloud protocol evaluations derived more broad themes than the heuristic evaluation.

These findings will be discussed in the next chapter.
Chapter 9 Discussion

This section will reflect upon the results of the study – providing a review of significant findings, together with interpretations, implications and any related factors that merit discussion.

This study has three hypotheses:

- First, applying the same usability evaluation methodologies of think-aloud protocol analysis, interviews and heuristic evaluation tested by Koykka et al. (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would also produce additional usability guideline categories.

- Second, think-aloud protocol analysis is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environment than a heuristic evaluation.

- Third, large-scale non-immersive, desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments because of complexity.

The discussion section will be presented in five parts:

Section 1 will discuss the four broad themes and the multitude sub-broad themes of derived from this study. They will be discussed in reference with Koykka et al. and other supporting literature to determine if they support other existing VE design guidelines or new ones are need to created be created, answering the first objective of this study.

Section 2 will reflect upon the results of comparing between the large- and small-scale VE systems to determine the answer to the study's third objective.
Section 3 will compare the experimental result with results found in the Koykka, et al., 1999 study with the resulting broad themes and sub-themes derived from the study. The results will also be discussed in reference with Koykka et al. and other supporting literature to determine answer the first objective of this study.

Section 4 will discuss and reflect upon the evaluation and analysis methods used in this study: think-aloud protocol, interviews and Nielsen’s heuristic evaluation to determine the answer to the study’s second objective.

Finally, section 5 will present some of the limitations of this research as well as suggesting future directions from this study.
9.1 Section 1: Broad Themes Analysis Experimental Results

The experimental results have identified 4 broad themes derived from using the Emergent Themes Analysis (ETA) approach on data resulting from a think-aloud protocol method and heuristic evaluations. The 4 broad themes are listed and described as follows:

1. Functionality - referring to the usefulness of or how well-designed were the VE systems.
2. Interactions – referring to the users’ ability to invoke behavioral responses to objects within the VE. This may be within the entire VE itself or a specific area of the VE environment. This include navigation and wayfinding, searching and browsing, object selection and manipulation and system control (Stuart, R. 2001).
3. Appearance - referring to the aesthetic presentation of the VE system along with any related textual, numerical, image, sound or animated information. This includes whether the information presented was cohesive, easy to read and understand, and the quality of images were acceptable that the users were satisfied in using the system.
4. User Comments - referring to comments provided by the user at any point of the evaluation including the interviews. Constructive or critical comments made by the users with regards to the VE, its presentation, and suggestions for improvement that the researcher could not classify as usability problems within the functionality, interaction or appearance broad themes. Additionally, user comments referring to the experimental procedure.

Sub-broad themes were identified that help derive the four broad themes. Each of the sub-broad themes is briefly described in the next section.

9.1.1 Functionality

Limited or lack of VE system status feedback

Limited or lack of VE system status feedback was derived from four themes identified from the Think-Aloud Protocol (TAP), Heuristic Evaluation (HE) and interviews. This theme refers to the system providing no feedback as to how the current state was achieved, lack of feedback to the user’s spatial location, orientation, lack of feedback as the current status of the system and lack of feedback given by the map when it is used.

Hidden system functionality

Hidden system functionality refers to the need for interaction objects and their behaviors to be made clear and visible to the user. Some issues that were identified include: “invisibility” of the system purpose and its use, and the user being stuck due to no clear “emergency” exits or "undo" options available.
**Hidden interaction object functionality**

Hidden interaction object functionality refers to interaction of objects presented within the VE system to be hidden. This differs from the Hidden system functionality above, as hidden interaction object functionality refers to interaction objects within Windows environment such as scroll bars and close buttons as well as the VE controller buttons.

**Limited freedom and movement within the VE system**

Limited freedom and movement within the VE system was also identified from the results analysis. Limited freedom and movement refers to the users limited ability to look thoroughly within various areas VE system. Movement within the VE of the evaluated systems was limited as users were only allowed to view certain areas of the environment, thus limiting their access within the VE world. In some areas of the evaluated VEs, the users are only allowed to take certain paths or view certain areas (like in the Wroxton Abbey and Richard Strauss House).

**Lack cross-platform availability**

Lack cross-platform availability on VE objects and its behavior was another theme derived from the heuristic evaluation but not from the TAP. This is perhaps due to evaluator's using both the Apple Mac and PC platforms to heuristically evaluate the systems.

**Lack of distinct functions between novice and expert**

Furthermore, lack of distinct functions between novice and expert users was also a theme identified from the heuristic evaluation but not from the TAP. This is perhaps due to Jakob Nielsen's usability heuristic assessing for flexibility and efficiency of use with respect to availability of accelerator for expert users.

**Help and documentation**

Help and documentation was a broad issue derived from TAP, HE evaluation and interviews. Problems with the clarity of the help, lack of system documentation frustrated the users.

P02 (0:59:21 - 0:59:39) - ... Even the help (rolling the mouse over the help button), I couldn't use the help. I don't know why it didn't really given me a good help (clicked on the help icon to bring up a text window with the help), I don't know.

P09 (0:37:13 - 0:37:26) - Ah, yeah, once I found out, like I read those instructions twice about looking up and down, and I didn't even really think to push that button. Once I did it, it was like it seemed a really simple thing to do but it didn't really say in the instructions that you had to hold the mouse button down. So I was just expecting to move it from left to right and up and down. So I had a bit of trouble finding that, and just a bit of confusion about what a priory was really.

Mills, S. and Noyes, J., (1999) suggests that when designing VE systems, aside from movement and image quality, specific system help for users is recommended.
The results from the Functionality broad theme indicate that a similarity exists between the derived sub-broad themes and Nielsen’s usability heuristics. Table 9-1 presents the relationship of some of the derived sub-broad themes to Nielsen’s usability heuristics.

**Table 9-1. Relationship between the Functionality sub-broad themes and Nielsen’s usability heuristics.**

<table>
<thead>
<tr>
<th>Nielsen’s Usability Heuristics</th>
<th>Functionality sub-broad themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of system status - The system should always keep users informed about what is going on, through appropriate feedback within reasonable time - persistence</td>
<td>Limited or lack of VE system status feedback</td>
</tr>
<tr>
<td>Match between the system and the real world - The system should speak the users’ language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real world conventions, making information appear in a natural and logical order.</td>
<td>Hidden system functionality Hidden interaction object functionality</td>
</tr>
<tr>
<td>User control and freedom - Users often choose system functions by mistake and will need a clearly marked 'emergency exit' to leave unwanted state without having to go through an extended dialogue. Support undo and redo.</td>
<td>Limited freedom and movement within the VE system</td>
</tr>
<tr>
<td>Consistency and Standards - Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.</td>
<td>Lack cross-platform availability</td>
</tr>
<tr>
<td>Flexibility and efficiency of use - Accelerators - unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater for both inexperienced and experience users. Allow users to tailor frequent actions.</td>
<td>Lack of distinct functions between novice and expert</td>
</tr>
<tr>
<td>Help users recognize, diagnose and recover from errors - Error messages should be expressed in plain language (no codes), precisely indicate the problem and constructively suggest a solution.</td>
<td>Help and documentation</td>
</tr>
<tr>
<td>Help and documentation - Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user’s task, list concrete steps to be carried out, and not be too large.</td>
<td>Help and documentation</td>
</tr>
</tbody>
</table>

The next section will discuss the interaction sub-broad themes derived from this study.

**9.1.2 Interactions**

**Real world conventions were not applicable in the VE refers to objects and behaviors within the VE system**

Real world conventions were not applicable in the VE refers to objects and behaviors within the VE system not meeting the user’s expectation when an action is applied to an object. These are objects and behaviors encountered in the real world that the users’ expect to be applicable in the VE world such as going through doors, being able to see what is outside a window etc. Issues identified as themes include object behavior such as in the Richard Strauss, when the user clicked on the table and the user it went out to another location. In a usable VE, meeting the user expectation is one of the key factors. This can be achieved by using real world metaphors that are clearly understandable (Bowman, D. A. 1999; Koykka, M., Ollikainen, R. et al. 1999).
**System exploration**

System exploration refers to the users need to explore and familiarize themselves within the VE. This is usually done through navigation and wayfinding particularly browsing to obtain different views and acquire an accurate “mental map” of their environment (Kaur, K., Maiden, N. *et al.* 1999; Stanney, K. M., Mollaghasemi, M. *et al.* 2003). This theme was derived from users stating that they needed to find out what is currently available not only within the presented VE but also its surrounds. Although each participant had the opportunity to explore the VE, some participants stated that they wished they paid more attention to the different areas of the VE. This is especially evident after they were asked to perform some of the searching tasks in during the TAP evaluation. This broad theme suggests that a need for clearer navigation tools is needed.

**Limited use of the provided navigational aids**

Limited use of the provided navigational aids refers to the use of maps and embedded arrows within the VE system. In this evaluation, issues that were identified include the divided attention between the provided map and the VE, the inaccuracy of the location representation, and unambiguous purpose of arrows. The design of a VE must therefore include appropriate visual cues and navigational aids, such as a compass or a map, to facilitate users’ acquisition of spatial knowledge (Darken, R. P. and Sibert, J. L. 1996).

**Difficulty in navigating within the system**

Difficulty in navigating within the system broad theme was derived from users not knowing how to move from one location to another. This includes users finding the “jumping” or “teleporting” way of moving from one place to the next disorienting (Villanueva, R. and Wong, B. L. W. 2001), confusing and a waste of time. Users also stated in the TAP evaluation that they preferred the movement between different locations to be more natural like that to the real world. So perhaps a transitional stage to imitate walking could be provided.

**Difficulty of users to pan within the VE**

Some users had great difficulty determining how to rotate/pan within the VE to view the surrounding area within a particular node. The users either found that they did not immediate know how to pan/rotate within the VE itself (in the Wroxton Abbey and Richard Strauss House) or they found that the rotation of the VE was too fast (in the Sydney Opera House, Wroxton Abbey and Richard Strauss House). The latter issue was also identified in Norris, B. E., (2001) as one of the activity breakdowns (QTVR Panning Sped) encountered by the user using a desktop photo-realistic VR.
Chapter 7: Experimental Results

**Searching for information and locations**

Searching for information and locations – as part of this study, the participants familiarized themselves with the VE systems during the TAP and HE evaluations. During these evaluations, participants searched for specific objects, where searching is the task of looking for a known target (Saretto, C. J. 1997), such as different locations or further information about the location and objects. The searching task was made even more difficult by the lack of VE system status feedback, hidden system functionality, hidden interaction object functionality, limited functionality of the provided navigational aids, and limited freedom and movement within the VE system as identified in the Functionality broad theme.

**A complete and clear relationship between the map navigational aid and the VR is missing**

This issue refers to users having difficulty searching for information and location. This, again, can be contributed to various factors such as the users' inability to form an accurate mental map within the short exploration time, the lack of feedback especially when a user moves from one location to another and the complexity of the VE system. For example, the Sydney Opera House and the Questacon Science Center is considered as a large, complex system with a number of nodes greater than 40 and vast amount of links that exists between them. This can be compared to the Wroxton Abbey and Richard Strauss House, which consisted of less than 10 nodes.

**Difficult for users to determine their current location.**

The users had difficulty determining their current location. This made the users confused about their location. Identified narratives like “I’m lost” or “I’m not sure where I am at the moment” support this sub-theme. This sub-theme is also related to the limited or lack of system status feedback that some or areas of the VE system failed to provide, again identified in the Functionality broad theme. Kaur et al. 1999 stated that appropriate information about spatial structure of the VE and location of target objects should be provided especially when navigating in a VE.

**Limited Field of View (FoV) movement**

This sub-broad theme is similar to the limited freedom and movement within the VE system sub-broad theme derived under the Functional broad theme. The difference between the two sub-broad themes is that limited FoV movement refers to the users “head-movements” and its ability to look within the VE system at different angles. For example, in the real world, we have an enormous amount of ‘degree of freedom’ (Eddings, J. 1994) that we are able to look up, down, left, right, move our head around. Users’ should be able to at least view 180 degrees in a presented VE (Bullinger, H. J. 1997; Villanueva, R. and Wong, B. L. W. 2001; Xiao, D. Y. 2000). The users experienced a limited FoV when looking through the system. This meant that in some areas of the VE, they were also able to pan with as little as 90
degrees and the maximum of 360 degrees on the horizontal axes. This is due to the different evaluated systems having different 'degrees of freedom' available.

Based from the derived sub-broad themes, some interesting results can be drawn such as a relationship exists between the functionality and interaction of a system. It would suggest that limited functionality within a VE system also contributes to hindering the users' ability to interact with objects within VE system. This is supported by similar issues were identified between the Interaction and Functionality sub-broad themes. Sub-broad themes like difficulties experienced by users in searching for information and locations and determining their current location from the Interaction broad theme can be related to Functionality sub-broad themes such as limited or lack of system feedback, limited functionality with system and interaction objects such as maps, limited freedom and movement within the VE. Furthermore, the findings also suggest that clear understandable and usable metaphors within VE systems may be needed. For example navigation, searching and movement metaphors needs to be clearly visible.

The next section will discuss the Appearance sub-broad themes.

9.1.3 Appearance

*Information presentation*

Information presentation refers to how interaction objects, as well as text, numerical, sound or animated information, icons, symbols, tone and language were presented within the VE system. Some of the themes that contributed to this broad theme include: Users did not know the meaning of the terms and acronyms used in the VE, there was no clear indication as to what the symbols and historical language references mean. Additionally, the amount of textual information was so great and poorly laid out that the users often skimmed through or not even read the text.

*VR presentation*

VR presentation refers to how the entire VR system was presented such as the arrangement and layout of the VE window, the maps, node labels, map levels (see Appendix A for examples), and embedded arrows. Users, particularly of the Wroxton Abbey, found the VE system to be tedious to use due to the presentation of the system. Some of the issues included the map being at a different 'eye-level' as the VE window, thus making the user scroll down to view the map and the phenomenal amount of "boring" text presented.

*Image quality*

The quality of the VE image was theme derived from the TAP evaluation. Image quality used in the creation of the photo-realistic VE, particularly in the Wroxton Abbey and the Richard Strauss House was poor that it prevented participants from zooming in and viewing certain
objects in greater detail, thus deterring some participants from exploring the environment further or completing search tasks. Quality of images and zoom levels were some of the issues found in Norris, B. E. (2001) and Villanueva and Wong (2001) paper. These findings support the issues found in this study.

**Location and size of hotspots**

Location and size of the hotspot links within the VE system affect the usability of a VE system (Norris, B. E. 2001; Norris, B. E. and Wong, B. L. 2000; Villanueva, R. and Wong, B. L. W. 2001). Without a clear indication of where the users are able to click and move from one node to another, the user was stuck within that location. Poorly placed and sized links gave users the impression that there were no links available to other places from their current location and the VE being poorly designed as location links should not be assigned on objects.

The sub-broad themes suggest that first impressions are made on appearances. The current appearance of the four evaluated VE systems provided the user with the impression that the VR, information, quality of images and location and size of hotspot presentations needs to be improved

### 9.1.4 User Comments

**User VE comments and suggestions**

Users made comments on and suggestions to the presentation of the VE. The comments were both critical and constructive. Some of the critical comments made include:

- **inconsistencies with object behaviors such as scroll bars and hotspot links (Norris, B. E. 2001; Xiao, D. Y. 2000),**

  P03 (0:15:27) - ...And I would like to zoom at this ornament (tapestries) possibly to get close to it already and maybe it’s, um, given a feeling of reality 'coz I’m probably standing on the floor, I will not be possible to get close from the floor to the ceiling and they will try to, uh, the zoom is like a feeling of still being at the same place, but more, standing at the same place and using your body and your head to get closer. For example a picture, rather than using your feet to walk, it more like standing on your feet and stretching your body to different directions if like when you drop something on the floor (zoom in) and when you bend down and pick it up from the floor (zoom out)...

  P09 (0:16:43) - ...It was my understanding that I’d be able to move from right to left like I was turning my head, once in these rooms, just to have a look around, up and down, look at the ceiling and look what’s behind me. But, I haven’t really been able to figure out how to do it though...

  P06 (0:41:44) - ...Ah there’s the window, I’d like to see out that window (zoom in using the plus button on the controller), but I can’t see out the window (Panning within the VR)...

  P08 (0:25:09) - (Clicking on the VR movie itself – no effect) I thought maybe by clicking on it, I might be able to zoom in onto something, but I can’t.

  P10 (0:57:39) - ...And there is also a scroll bar, scroll down the page (for the text window, clicking on this now). The thing on the mouse [middle button scroll bar] I don’t know if it should work or not (clicked on Close to close the window).
the Field of View (FoV) (Villanueva, R. and Wong, 3. L. W. 2001) that they face when they arrive at a new node, and

P09 (0:18:47) - ...I would have thought there would have been a hotspot to take me back there. There's just ah, ah hang on, there's one, it's just a picture on the wall, (clicked on the hotspot on the picture). I should get a photo of that picture...Umhum. (clicked on the Back Gray arrow on the screen to return to the Great Hall - FOV is the other way around - should face downwards to the floor but again, facing picture). I'm just seeing if these other paintings (beside the one with the hotspot, clicking - no effect). There's just the one in the middle you can look at.

confusion in the way the system was supposed to work due to various object layouts.

P09 (0:18:47) - ...I would have thought there would have been a hotspot to take me back there. There's just ah, ah hang on, there's one, it's just a picture on the wall, (clicked on the hotspot on the picture). I should get a photo of that picture...

P04 (1:08:41) - And, so, when I was randomly clicking around the little screen, it took me somewhere where I didn't want to go. It's quite hard to actually tell that that's a door.

P03 (0:07:50) - This is the main entrance, oh yeah, (clicked the embedded hotspot again to go back into the hallway), I thought it was this door (on the right) rather than this entrance (forward that goes back outside) maybe the feeling of getting back into a room like this looks far away from the door. (The entrance door) This looks more like a window than a door to me. Or maybe it's a hallway between the doors and the...Yep, there's probably a room between the hallway and the main entrance that makes it a little bit strange to me.

Some of the constructive comments made by the evaluators include:

- the good use of a map and the VE,

P02 (0:26:20) - ...But ah, it's good that I can see everything from here (rolling over the 3D map)...  
P11 (0:01:30) - I'm just seeing that at the bottom (the 3D map) and trying to put the two together (the VR and the map). (Now, panning over the VR to have the yellow arrows appears as you rolled over an area of the VR). That's quite cool.

P07 (0:18:21) - I think it's good that it's got both the map and the window, the VR window.

- the option of being able to customize settings such as turn off the interactive robot from Questacon Science Center, and

P08 (1:07:17 - 1:07:20) - Oh, just going back to what I didn't like. I didn't like the robot after a while, ...Because of the noise and because it slowed you down, because you had to wait until it had gone through its functions, so, what I did like was that you could turn that off. Laugh. Which I did after a while, when I read the side menus.

- automatic actions such as windows scrolling as you place your mouse cursor over a scroll bar.

P04 (1:25:06) - the little text sections with the scrolling, Ahm, it's quite good having it when you don't have to click...

Some of the suggestions that the evaluators provided include:

- a better way of navigating between nodes,

P10 (1:29:09) - ...So, I think it would have been easier, if we had, like this is very nice, very nice virtual thing, um, but instead of all these buttons, like, all these dots that I have to, for example the task is asking me to go to Concert Hall Foyer South. And I have to find out which one of these dots are the exact location. If there was like a combo box thing, which contains all these, the names of all these Halls and Foyers, or whatever, that would be easier, just like going through that menu.
the appearance of a “tool tip” within the VE environment to indicate to the user where they are, what links are available within the current location, and how can they quickly find their way out of the current location.

P11 (0:30:04) - I thought it needed some way of telling you where you have been and how to go back.

The evaluators also suggested that:

- navigational aids such as the map should be at the same level as the VE window and

P03 (0:15:27 - 0:18:49) - And maybe I would like to have this map on the right hand side a little bit at the same level as the scroll window. It would be nice to have it the same level as the picture (VR). Okay...Why? Because all of the hotspot would be visible 'coz the hotspot number 1 is covered, can't see the whole map on the map, you can't see the whole map and it will decrease visibility (moved the scrollbar up and down) and ease the navigation.

P09 (0:44:08 - 0:44:18) - This map (pointing to the 1D map), it wasn't really like ah, find that, there's another screen apart from this one, it's sort of half cut off. I thought maybe, umm, if the screen could be arranged better. Maybe the map in one of the corners, up the top so it's always visible instead of having to scroll down to find it. But, umm, yeah apart, I think if I had grasped the instructions a little easier, figured out at the start, once you know how to do it, it's pretty easy to find your way around.

- that drop-down lists or combo boxes containing all the different locations that they could visit be available. This was especially prominent in the large-scale VE systems.

P01 (0:05:46 - 0:05:53) - it will be nice if I'm in here and they have a list of stuff, of places so I that can just click on in. It's like they want me to go around to look one by one but if they have a list already here it'll be faster if I know what I want to look but for those people who just want to roam around it'll be a very good place to roam around but sometimes people don't have much time.

P03 (0:29:14) - Maybe I think it would be nice to have not all the scenes (available) not in a text paragraph. Maybe have them instead in a list.

User Experiment comments

Furthermore, the users were able to comment on the experiments themselves and suggested that some of the task questions were ambiguous.

P11 (0:23:51) - (Reading the task sheet – Task 4b, right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom in) I suppose clicking in the zoom in, makes it closer. Is that what's meant by making it bigger?

P05 (0:36:55 - 0:37:24) - Um, (0:37:00) Actually just, (rolling over the 3d orange balls on the 3D map to bring up location labels), um, you had "Front Entrance" or something over here. I just assumed that the Front Entrance was the Patio 'coz I think it says, it's different 'coz I think because this is called the Foyer, and this is the Patio. So I wasn't sure if the patio is the Front Entrance.

P08 (0:38:55) - ...(Clicked on the embedded hotspot to the Foyer), I'll, is that what meant by the spinning spiral, that thing?

P04 (1:33:20 - 1:33:45) - Um, I couldn't find the kitcher. And the mask question, it says by the table by the window. If I was looking at the mask it was referring to I would have said it like "above the table by the stained glass window". And also the mask was blurred so that what you can only see is this head-shaped thing with like an apricot color...

P06 (1:03:50 - 1:04:12) - ... one of the questions was a little bit (ambiguous), I think it was just cos I was, I wasn't sure about the piano. I was looking for a baby grand and it mentioned that in there was a grand, it was actually a grand, and I wasn't sure if there was a difference, cos I don't know much about pianos anyway. Whether or not a baby grand was going to be a smaller grand piano or not, so. I'm aware they may have had two pianos in there.
However, they found that exploration of the system before being asked to conduct a list of tasks was good and that the video recording of the screen, mouse and keyboard, rather than their faces made them more comfortable with doing a think-aloud.

The sub-broad themes suggest that user comments and suggestions valuable insight to the usability of the photo-realistic VE systems. This is particularly true when comments made re-enforce usability issues encountered during the evaluation of the system.

9.1.5 Summary

Using the emergent themes analysis (ETA) approach, four broad themes were identified that can be categorized as usability design guidelines for non-immersive, desktop, photo-realistic virtual environments. They are functionality, interaction, appearance and user comments.

Functionality of non-immersive, desktop, photo-realistic virtual environments should present system and interaction object functionalities in a clearly understandable manner. Both novice and expert users should be able allowed at least 180 degrees of freedom when viewing systems in multiple platforms. The users should also have the flexibility to use the system in a manner in which they are comfortable with e.g. keystroke versus mouse clicks.

Interactions within non-immersive, desktop, photo-realistic virtual environments should allow for system exploration so that browsing and searching of information about objects, viewing and moving between locations can easily be achieved. By doing so, an accurate user mental map of the VE can be derived. Non-immersive, desktop, photo-realistic VEs should also be presented in an optimal fashion in clearly laid-out sections that allow quick and easy assimilation of VE objects and related information. Links within the VE like hotspots, should be clearly visible appropriately assigned to objects and informative, when required.

Finally, user comments and suggestions should also be considered when designing VE systems. After all, they are the ones who will be using the system.
9.2 Section 2: Large-scale versus small-scale VE systems

The results between the large- versus small-scale VE systems indicate that a greater number of functionality, interaction and appearance problems were found in small-scale VE systems. This is contrary to this study’s hypothesis that large-scale VE systems would have more usability problems because of complexity than small-scale systems.

Complexity is characterized by attributes of significant interactions, high number (of parts, degrees of freedom, or interactions), nonlinearity, broken symmetry etc., (Yates (1978 cited in Backlund, A. 2003; Myers, M. D. 1997)) and are characteristics of the large VE systems. It would seem logical to deduce that due to the complexity in size of the large-scale system that it would present more usability problems. However, small-scale VE systems still had a greater number of usability problems. This result could be attributed to the large-scale VEs used in this study included better navigational aids such as embedded arrows to indicate links as well as the direction that the user would travel to if activated compared to small-scaled VE systems which had fewer number of nodes, making it easier to navigate and relate each location to one another. Furthermore, these embedded hotspots were also linked to a separate 3D map that provided a clear overview of the entire location and that changes dynamically as the user travelled to that destination. Additionally, the large-scale VE systems could have been constructed with a more generous financial budget than the small-scale counterparts. It would be interesting to evaluate if a large-scale VE system, with limited resources, would result in the same way. This could be an area for future study.

9.3 Section 3: Broad themes and sub-themes versus Koykka et al.

Section 2 provides a comparison between the broad and sub-broad theme results with Koyykka et al.’s additional usability categories. The main aim of this study was to determine whether applying the same usability evaluation methodologies of think-aloud protocol, interviews and heuristic evaluation tested by Koykka, Ollikainen, Ranta-aho, Milszus, Wasserroth and Friedrich (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would also produce additional usability guideline categories.

Koykka et al. (1999) suggested three additional categories to address the usability problems related in non-immersive, 3D, multi-user environments. They were:

- 3D environments should provide support for orientation, navigation and movement – providing feedback and support such as a start-up screen to explain the basic ways to
move and use of functionalities would solve the inefficient way of accessing the different web services and content.

- Real world metaphors have to be clearly understandable – functional consistency and analogies with the real world should be self-explanatory and would help facilitate the learning process of use of the available services.
- Avoidance of delay and waiting periods in performance.

These categories were compared against the experimental results.

9.3.1 3D environments should provide support for orientation, navigation and movement

The results would indicate that some sub-broad themes from the Functionality and Interaction broad themes support Koyyka’s additional category for orientation, navigation and movement support. Some of the Functionality sub-broad themes that support Koyyka’s category include limited or lack of system feedback, help and documentation, limited use of navigational aids and hidden system and interaction object functionality and freedom and movement. These sub-broad themes contribute to the difficulty of users in determining their current location, to move, navigate and pan within the virtual environment, and therefore interact with the VE.

9.3.2 Real world metaphors need to be clearly understandable

Koyyka’s additional category of “Real world metaphors need to be clearly understandable that the analogies match the real world” making it self-explanatory is supported by the Functionality, Interaction and Appearance broad themes. Some sub-broad themes from the Functionality broad themes that support this category include hidden system and interaction object functionality. With regards to the Interaction sub-broad themes, real world conventions were not applicable in the VE refers to objects and behaviors within the VE system, difficulty in navigating and panning within the VE and the users’ limited FoV. Although photo-realistic images were used to create the VE s, its appearance and presentation still affected the users understanding and usability of the system. For example, the location and size of hotspots that link to other nodes or objects were inconsistent in size and presentation that some were available in “expected” objects within the VE and some were not. Furthermore, this theme, derived from TAP and HE data, did not meeting the user’s expectation when an action is applied to an object. These are objects and behaviors encountered in the real world that the users’ expect to be applicable in the VE world. Issues identified as themes include object behavior such as in the Richard Strauss, when the user clicked on the table it went out to another location. In a usable VE, meeting the user expectations’ by allowing them to interact with the VE as if they are in the real world is one of the key factors. Again, this supports Koyyka’s additional category that real world metaphors need to be clearly understandable. In addition, by ensuring that geographical metaphors (e.g. maps) are clearly presented and easily
understandable, system functionality and interactions within the VE will also be more visible, making the system more usable.

9.3.3 Avoidance of delay and waiting periods in performance

The Functionality sub-broad theme of limited or lack of feedback such as the current status of the system provides support Koykka’s third additional category for “Avoidance of delay and waiting periods in performance”. This theme was derived from TAP narratives and HE findings such as “I don’t know what’s happening”, “I’m just going to click on the window again and see what happens”. Clear system feedback, especially when users are interacting with the system would avoid user delay as well as frustration.

9.3.4 Summary for the Koykka et al. and experimental results

Based on these findings, it can be concluded that application of Koykka et al. (1999) comparative evaluation methods to a non-immersive, desktop, photo-realistic virtual environment, does produce additional usability design categories similar to the Koykka et al. study conducted in 1999. In this study, four categories were derived as broad themes. These are functionality, interaction, appearance and user comments.

9.4 Section 4: Evaluation and analysis methods

This section will address the second objective of this study: to determine whether think-aloud protocol or usability heuristic evaluation is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environment. This section will briefly discuss the think-aloud protocol, heuristic evaluation and emergent themes analysis approach methods used in this study.

9.4.1 Heuristic evaluation

As previously presented in Chapter 4 and Chapter 6, heuristic evaluation is an informal usability inspection method of finding usability problems in a user interface by having a small set of expert usability evaluators examine an interface and judge its compliance against usability principles also known as heuristics. This study used Jakob Nielsen’s ten usability guidelines to evaluate the four VE systems. The easy and quick implementation of this technique using a small number of experts to identify a large proportion of interface problems was a great advantage. In this study, although there was a limited number of usability issues identified compared to the think-aloud protocol, it was the heuristic evaluation method that provided interesting usability problems such as the lack of help and system documentation and the limited field of view of the user that allowed for interesting patterns to emerge. However, it is important to note that the identification of interface problems were limited to the heuristics used during the evaluation. This is indicated by the results in this study.
9.4.2 Think-aloud protocol

As previously presented in Chapter 4 and Chapter 6, think-aloud protocol is a form of user testing where the user's thoughts, feelings and opinions while interacting with the system are videotaped for later analysis. Using the think-aloud protocol in this study has elicited a better understanding of the VE system functionality, interactions between the user and the system, and its design and presentation. This study has provided insights and exposed more usability issues that were not possible with the heuristic evaluation such as indicated in the research methods review. However, some disadvantages of this approach include the unnatural environment of the user, such as the user was not always able to voice-out their thoughts, and the vast amount of effort required to transcribe the data. These phenomena were encountered in this study.

9.4.3 Emergent themes analysis (ETA) approach

In Chapter 6, emergent themes analysis was described as “an iterative distillation process” developed by Wong and Blandford (2002) to help extract design insights by identifying themes and decision strategies from voluminous interview data from real-time operational environments (namely emergency ambulance dispatch). Its exploratory and flexible nature allowed for themes to emerge from vast quantities of narratives, like interview transcripts. For example, when think-aloud and interview narratives or heuristic results do not “belong” to any identified broad themes in this study, new themes were created, which is an advantage. However, using the ETA approach also had some limitations. Limitations such as how many iterations of the distillation process needs to be done in order to achieve a broad enough theme. Also within each of the narratives, there are several themes that can be identified – how should these be analyzed and categorized. With regard to the analysis of the experimental results in this study, the question also raises issues about comparative assessment of already derived broad themes like that in the between large- and small-scale. The question is ‘how do we analyze those themes that were only found in one of the large-scale VE but not in the small-scale systems.’

9.4.4 Summary

In this study, the results indicated that think-aloud protocols identified a greater number of usability problems compared to heuristic evaluation due to the freedom and flexibility with which the user can conduct a think-aloud. This freedom and flexibility is also true with the emergent themes analysis as it allowed patterns to emerge.

The evaluation and analysis methods used in this study presented some limitations such as the amount of time and effort to conduct such evaluations and analyze the results. Results found in this study, would indicate that a combination of the two qualitative research methods is
recommended. The triangulation of the two techniques allowed non-obvious problems to become more visible with a greater number of usability problems being identified. This suggests that no one method is more effective when used for evaluating usability. This is why triangulation, which is the use of one or more research methods in a study, is recommended (Denzin, N., K. and Lincoln, Y. S. 2000) as it provides multiple perspectives when interpreting a single set of data, neutralizing the bias inherent in particular data sources, investigators and methods (Creswell, J. W. 1994).

The next section will briefly discuss the limitations of the current study and future research.

9.5 Section 5: Limitations and Future Research

This section will briefly discuss the limitations of the current study and suggest any future research.

9.5.1 Limitations

9.5.1.1 Time constraints

As participants and expert evaluators were students of the Information Science course at the University of Otago, the study had to fit within the course curriculum. As a result, both qualitative evaluations were conducted within a two-week timeframe.

9.5.1.2 Complexity of ETA

Think-aloud protocols and interviews used in Phase One of the study and the Emergent Themes Analysis (ETA) approach for the analysis of the experimental results takes more time and experience to master compared to a usability heuristic evaluation, which is checking for properties of user interface conformance using a set of guidelines. This was the first time ever the researcher had used and applied those research methods and so there was the time taken to gain the experience in order to conduct think-aloud protocol, interview method and the ETA analysis effectively on a large scale such as this. Perhaps using a known qualitative analysis tool like NVivo (http://www.qsr.com.au/) would have made the analysis of the Think-aloud protocols and interviews easier to analyze as NVivo allows the user to create and assign specific tags to similar instances of data.

9.5.1.3 Experimental Methodology

Differences in the web-based QTVR system

Although the researcher tried to create pairs of virtual environments that are similar in scale, interaction and navigation, the individual differences may have affected the experimental result. For example one of the small environments used a 2D map as a navigation aid, while the other small environment used a complex 3D map. Similarly, in one of the large scale
environments, there were 82 nodes, while the other large environment has less than half of this (40 nodes). These differences may have affected the results.

**Experiences of the users and evaluators**
The prior experience of two of the twelve participants using virtual environments may also have skewed the results.

**Two Computer Operating Systems**
The different equipment and platforms (Mac versus PC) introduced another variable that may have also affected the results as the evaluators used either one of the equipment and platforms to conduct the heuristic evaluation.

**Lack of a pilot study**
One of the limitations of the experimental study is the lack of a pilot study before running the full experimental study. In hindsight, running a pilot study would have identified problems with the experimental design such as the task sheet wording, which would have likely prevented a User Comment sub-broad theme of “Feedback from users that wording of the task sheet was ambiguous” to be derived.

**Different (or lack of) experimental tasks in the heuristic evaluation**
In hindsight, another limitation of the experimental study is the differences in the way the user/evaluator conducted the evaluation. In the think-aloud protocol evaluation, users were asked to perform specific search tasks. This was not the case for the heuristic evaluation as no specific search tasks were given. Evaluators were asked to assess the systems' usability based on specific guidelines. It is difficult to determine how the different conditions would have affected the results. Perhaps the result may have indicated a greater number of commonly identified usability problems between the heuristic evaluation and the think-aloud protocol.

### 9.5.2 Future Research

#### 9.5.2.1 Alternative VE usability evaluation methods available

Since the inception of this study, a greater number of virtual environment evaluations have been conducted and developed. For example, design questionnaires like Kalawsky’s VR Usability Questionnaire (VRUSE) and Stanney et al.’s Multi-criteria Assessment of Usability for Virtual Environments (MAUVE) could have been used to evaluate usability of non-immersive desktop photo-realistic VE and help determine if non-immersive desktop photo-realistic virtual environments are more usable.

Furthermore, other traditional usability evaluation techniques may also have been used. Methods like co-discovery learning, where 2 participants attempt to perform the tasks together and help each other out while trying to explain what they are thinking, is a more
natural way to verbalize thoughts during a test; and retrospective testing, where the researcher and the user review taped sessions (usually videotaped) of the user conducting the test after the user has performed the test, provides more value and convenience to the study as the researcher can stop the tape and question the user in more detail without the interference during the test. These methods are more natural and less interruptive.

Additionally, the proposed broad theme usability guidelines can be applied in a design of a desktop, photo-realistic virtual environment. Studies can be conducted that will re-assess the VR for usability. Furthermore a study can be conducted with people who have actually experienced the environment, i.e. someone who has actually visited the Sydney Opera House, to determine whether previous experience of visiting a place have made traversing and searching within the VE much easier.

Furthermore, the broad themes may be used as guidelines to investigate the use of VR on mobile computers so that users can simultaneously experience reality and the VE.

9.5.2.2 Large- versus small-scale VE systems evaluation of other virtual environments

Further study of large- versus small-scale VE systems can be conducted using other usability evaluation methods. Some interesting studies could include not just evaluation of large- versus small-scale non-immersive desktop photo-realistic VE systems, but also of other types of VE systems such as non-immersive desktop 3D VE systems. For example, a comparative study between different VE scales and immersive versus non-immersive desktop VE systems.

9.5.2.3 Quantitative analysis of the think-aloud protocol data

Finally, the vast amount of data collected in this study, an analysis of the think-aloud protocol videotapes at each stage of the evaluation: exploration, assigned tasks performance and interviews can be re-analyzed for patterns of interactions (Kaur, K., Maiden, N. et al. 1999) or decision-making. A quantitative study could also be conducted by analyzing the time taken to perform certain actions and tasks, the user keystrokes and screen mouse movements to determine if certain VE systems were more difficult to search or navigate in due to the number of keystrokes or error recoveries that the user had to make.

9.6 Chapter Summary

This chapter discussed the four major findings from this study. These findings include:

Using the emergent themes analysis approach, a host of sub-broad themes were identified to become four broad themes from the think-aloud protocols and heuristic evaluation. These broad themes are functionality, interaction, appearance and user comments.
Small-scale VE systems contained more usability problems that the large-scale VE systems, which was contrary to the logical conclusion that large-scale VE systems would have more problems due to its complexity.

Additional usability design categories were identified when think-aloud and heuristic evaluations are applied to non-immersive desktop photo-realistic VE systems. Functionality, interaction and appearance are similar to Koyyka et al.'s findings of support for orientation, navigation and movement, clearly understandable real world metaphors and efficiency in performance, when the same methods were used to evaluate non-immersive desktop 3D multi-user VE systems. The user comments broad theme was an additional theme that was not present in the Koyyka et al. results.

Think-aloud protocol analysis identified more usability problems than the heuristic evaluation of non-immersive, desktop, photo-realistic VE systems. It is the open and flexible nature of the think-aloud protocol available to the user that allowed patterns to emerge and derived using the emergent themes analysis. However, the results indicate that a triangulation of the two qualitative methods allowed for an even greater number of usability problems to be identified and is therefore recommended.

The next chapter presents the conclusions found in this study.
Chapter 10  Conclusions

This study is about the evaluation of non-immersive, desktop, photo-realistic virtual environments using a think-aloud protocol and heuristic evaluation to elicit data so that broad themes of usability problems using the Emergent Themes Analysis approach may be derived.

There were three hypotheses to this study:

- First, applying the same usability evaluation methodologies of think-aloud protocol analysis, interviews and heuristic evaluation tested by Koykka, Ollikainen, Rantah, Milszus, Wasserroth and Friedrich (1999) on a non-immersive, 3-Dimensional (3D) multi-user interface virtual environment to a non-immersive, desktop, photo-realistic virtual environment would also produce additional usability guideline categories.

- Second, think-aloud protocol analysis is a better evaluation method for identifying usability problems in a desktop, photo-realistic virtual environment than a heuristic evaluation.

- Third, large-scale non-immersive, desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments because of complexity.

There are four conclusions that can be derived from this study:

First, the results would indicate that applying a think-aloud protocol and heuristic evaluation method to a non-immersive desktop photo-realistic virtual environment produced the similar usability guideline categories suggested in the Koykka et al. study. This answers the first aim of the current study.
Second, using the emergent themes analysis approach, a distillation process resulted in voluminous qualitative narratives being attributed to four broad themes: functionality, interaction, appearance and user comments. These were identified and are proposed as design usability guidelines for non-immersive desktop photo-realistic virtual environments.

Third, think-aloud protocol analysis identified a greater number of usability problems in a desktop, photo-realistic virtual environment than a heuristic evaluation. However, from the analysis of the experimental data, triangulation of the two qualitative methods allowed non-obvious problems to become more visible with a greater number of usability problems being identified using the emergent themes analysis approach. This answers the second aim of the current study.

Finally, the results indicate that in using both the think-aloud protocol and the heuristic evaluation, small-scale non-immersive desktop photo-realistic virtual environments identified a greater number of usability problems than the large-scale non-immersive, desktop, photo-realistic virtual environments. This is opposite to what is suggested from the third aim of this study, that large-scale non-immersive, desktop, photo-realistic virtual environments will have more usability problems than small-scale non-immersive, desktop, photo-realistic virtual environments because of complexity.

**Final Words**

This study found that possible new design guidelines could be identified for the design of non-immersive desktop, photo-realistic virtual environment; triangulation of the think-aloud and heuristic evaluation methods resulted in identifying a greater number of usability evaluations and that small-scale VE systems used in this study contained more usability problems compared to large-scale VE systems. With these results in mind, it is hoped that this provides a beginning to future developments of usability evaluation methods for non-immersive desktop, photo-realistic virtual environments such as the applying other VR evaluation methods like VRUSE and MAUVE, or co-discovery learning and retrospective testing to non-immersive desktop, photo-realistic virtual environments and conducting large- and small-scale VE systems evaluation on other types of VE systems. Regardless of its future use, usability evaluations of *any* virtual environments are still needed.
References


References


References


Appendix A: Virtual Environments
The following are the URL addresses of the photo-realistic virtual environment websites used for the evaluations.

**A1. Sydney Opera House (Sydney, Australia)**


This is the starting panoramic VE of the Sydney Opera House. The following numbers indicate each component of the VE.

<table>
<thead>
<tr>
<th>Number</th>
<th>Component Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The VE window. This is the main VE window where the user can pan or rotate around to have a look at the location. Within this location, there are embedded yellow arrows that indicate that the user can click on. When clicked, the window changes as it loads up another VE location or some text.</td>
</tr>
<tr>
<td>2</td>
<td>The 3D Map. This is a 3D map representation of the area. As the user moves from one location to another, the view of the 3D map changes. Within the 3D map are yellow balls to indicate areas where there is a panoramic VR. The user can directly click on these yellow balls to view that particular location on the VE window.</td>
</tr>
<tr>
<td>3</td>
<td>The Map Level. The map level provides the user with an indication of how many levels that the user can visit. There are four levels available with the SOH. From the picture, it indicates that the user is at the Shell Level, which refers to outside roof shell of the SOH.</td>
</tr>
<tr>
<td>4</td>
<td>Compass or Orientation Arrow. There is an orientation arrow provided within the 3D map. Its purpose is to indicate to the user their current field of view.</td>
</tr>
<tr>
<td>5</td>
<td>Location Label – The location label presents the user the name of their current location and their spatial orientation such as whether they are facing North, South, East or West.</td>
</tr>
</tbody>
</table>

![Figure A1-1. The start-node of the Sydney Opera House.](image-url)
A2. Questacon Science Center (Canberra, Australia)


This is the starting panoramic VE of the Questacon Science Center. There are at least four different levels that contain panoramic VEs in them. The following numbers indicate each component of the VE.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The VE window. This is the main VE window where the user can pan or rotate around to have a look at the location. Within this location, there are embedded green spirals that indicate that the user can click on. When clicked, the window changes as it loads up another VE location or some text.</td>
</tr>
<tr>
<td>2</td>
<td>The 3D Map. This is a 3D map representation of the area. As the user moves from one location to another, the view of the 3D map changes. Within the 3D map are orange balls to indicate areas where there is a panoramic VR. There is also a &quot;view beacon&quot; that indicates the user's current view (which is visible in the second screenshot). The user can directly click on these yellow balls to view that particular location on the VE window.</td>
</tr>
<tr>
<td>3</td>
<td>The Map Level. The map level provides the user with an indication of how many levels that the user can visit. There are five levels available with the Questacon Science Center.</td>
</tr>
<tr>
<td>4</td>
<td>Text Description – Some description of what the particular location is about can be found here. Some movie clips are also presented here on the right hand side of this area.</td>
</tr>
<tr>
<td>5</td>
<td>Location Label – The location label presents the user the name of their current.</td>
</tr>
</tbody>
</table>

![Various screenshots of the Questacon Science Center VE](image)

Figure A2-1. This is the start page of the Questacon Science Center. At the start of the tour, there are some note tips that the user reads and then closes to provide them with some information as how to navigate their way around.
Figure A2-2. This is an inside view of one of the locations within the Questacon Science Center called the Drum Ramp.
A3. The Wroxton Abbey (Oxfordshire, England)

URL: [http://www.wroxtonabbey.org/index1.html](http://www.wroxtonabbey.org/index1.html)

This is the starting panoramic VR of the Wroxton Abbey. There is only one level with this system. This panorama shows the Wroxton Abbey Entrance Drive. The following numbers indicate each component of the VE.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The VE window. This is the main VE window where the user can pan or rotate around to have a look at the location. Within this location, there are embedded hotspots that indicate that the user can click on. Usually indicated by a hand pointing on the globe. When clicked, the window changes as it loads up another VE location or some text.</td>
</tr>
<tr>
<td>2</td>
<td>A 3D Map. This is a map representation of the area. As the user moves from one location to another, the view of the map changes with the movement of the cross (X) marking the user’s current location. Within the 3D map are letters and numbers to indicate areas where there is a panoramic VR. The user can directly click on these to view that particular location on the VE window.</td>
</tr>
<tr>
<td>3</td>
<td>Text Description – Some description of what the particular location is about can be found here.</td>
</tr>
<tr>
<td>4</td>
<td>Location Label – The location label presents the user the name of their current location.</td>
</tr>
</tbody>
</table>

---

**The Virtual Wroxton Abbey Tour**

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**Seven Hundred Years of History**

A history of Wroxton Abbey covers over seven hundred years from medieval priory, through Jacobean mansion and family home, to warehouse and apartments, and finally a campus of an American college. Changes in use have aided its survival and each change in occupation has left its mark upon the building.

This “Wroxton Abbey Entrance Drive” scene connects to scene 2 “Approaching the Abbey Main Entrance” and scene A. “Preview of Wroxton Village.”

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Drag left, right, up, or down to pan the view. Click on the hotspots (when the cursor changes) to go to a different location.

---

Figure A3-1. The start node of the Wroxton Abbey.
Early History

Ownership of the Wroxton manor is recorded as early as 1089. Michael Bovis, a clerk at Wroxton founded an Augustinian priory in 1216 or 1217.

Following the dissolution of monastic properties in 1536, Sir Thomas Pope, treasurer of Henry VIII's Court of Augmentations, purchased the lease to the land and monastic remains. He never lived at Wroxton, but after he founded Trinity College Oxford and endowed it with the Wroxton properties, the college was obliged to renew the lease of the estate to the male heirs of his brother John.


Figure A3-2. This is one of the inside panorama VR within Wroxton Abbey. This is the view from the Entrance Hallway.
A4. Richard Strauss’ House (Garmisch, Bavaria)

URL: http://www.richardstrauss.at/html_e/02_privat/0fs_index.html

This is the starting panoramic VR of the Richard Strauss House. There is only one level with this system. This panorama shows the Façade, which is the outside area of the house. The following numbers indicate each component of the VE.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The VE window. This is the main VE window where the user can pan or rotate around to have a look at the location. Within this location, there are embedded hotspots that indicate that the user can click on. Usually indicated by a hand pointing on the globe. When clicked, the window changes as it loads up another VE location or some text.</td>
</tr>
<tr>
<td>2</td>
<td>A 3D Map. This is a map representation of the area. The user may move from one location to another by clicking on an area on the map labelled with a number. Once clicked, the panorama will load into the VE Window (1).</td>
</tr>
<tr>
<td>3</td>
<td>Text Description – Some description of what the particular location is about can be found here.</td>
</tr>
<tr>
<td>4</td>
<td>Location Label – The location label presents the user the name of their current location.</td>
</tr>
</tbody>
</table>

![Virtual Tour - Microsoft Internet Explorer](image_url)

Figure A4-1. This is the Façade. The outside area of the house.
Appendix B: Ethical Approval
Appendix B: Ethical Approval

ETHICAL APPROVAL AT DEPARTMENTAL LEVEL OF A
PROPOSAL INVOLVING HUMAN PARTICIPANTS (CATEGORY B)

NAME OF DEPARTMENT: Information Science

TITLE OF PROJECT: Appropriateness of Heuristic Evaluation in Photo-realistic, Desktop Virtual Environments

PROJECTED START DATE OF PROJECT: September 2002

STAFF MEMBER RESPONSIBLE FOR PROJECT: Rochelle A. Villanueva

NAMES OF OTHER PARTICIPATING STAFF: Dr. B. L. William Wong

BRIEF DESCRIPTION OF THE PROJECT: Please give a brief summary (approx. 200 words) of the nature of the proposal:

The purpose of the project is to investigate the appropriateness of heuristic evaluation for desktop, photo-realistic, panoramic virtual environments (VEs).

An experimental approach will be used to gather a combination of quantitative and qualitative data to elicit interaction and usability issues arising from the use of VE systems.

Participants will be asked to participate in a two-session experiment: perform specific tasks using a VE while participating in a think-aloud protocol (Session 1) and conducting a heuristic evaluation of a VE system (Session 2).

Session 1 – Perform a list of tasks, to the best of their abilities, using one of the pre-selected VE from the World Wide Web (WWW) while verbalizing their thoughts (think-aloud) as you use the VE system. They will be asked to explore, navigate and search within the VE.

Session 2 – Participants in this session will be asked to evaluate, record and collate their findings using one of the pre-selected VE using heuristics.

As the participants conduct each session, the experimenter will record qualitative data (response to interviewers questions and comments made through the think-aloud protocols) observed using a digital video camera recorder. Quantitative data (such as time taken to complete the task) will also be recorded.

It is intended at the conclusion of the experiment, areas of tasks and heuristic conformance or violation can be identified that will either support or reject the appropriateness of heuristic evaluation in desktop, photo-realistic, panoramic virtual environments.

DETAILS OF ETHICAL ISSUES INVOLVED: Please give details of any ethical issues which were identified during the consideration of the proposal and the way in which these issues were dealt with or resolved:-

Participants are students of the Information Science undergraduate course INFO341 Human-Computer Interaction or associated with members of the University of Otago. They should not be familiar with the use and location of the desktop, photo-realistic, panoramic virtual environments in the experiment.

Statistical data will be collected from the participants. Participants' names and identities will not be recorded nor the participant be identified by any other information to be collected. All information collected will be treated in strictest
confidence and anonymity. Pseudonyms such as Participant 1 will be used to indicate each participant with any personal data and will be aggregated to provide no traceable links to any individual participant. Access to any data is limited to the supervisor, involved staff and the members of the INFO341 class.

Participants will be made aware of what type of information will be collected from them (i.e. age group, gender, familiarity with the location). Each participant will be briefed as to what the experiment is about verbally and by an information sheet. To confirm understanding of expectations from both parties (participant and researcher), each participant will be asked to sign a consent form, and the form will be collected by the researcher. Each participant will have complete control over the information and are asked to provide data as accurate as possible based on their interpretation of the questions. Any information that a participant may require regarding this project will be freely available to them on request.

Participants will not experience any physical or psychological harm or discomfort. Participants can freely withdraw from the project without any disadvantage to themselves.

All experiments (and collected data such as video recordings) will be conducted (and stored) within the University of Otago in the premises of the Information Science Department. Any data collected will be either destroyed upon the completion of the research or forwarded to the Information Science Department for safe storage for five years and eventual disposal.

**ACTION TAKEN**

- [ ] Approved by Head of Department
- [ ] Approved by Departmental Committee
- [ ] Referred to University of Otago Human Ethics Committee
- [ ] Referred to another Ethics Committee

Please specify:

Date of Consideration: ........................................

Signed (Head of Department): ..................................
APPRIOPRIATENESS OF HEURISTIC EVALUATION IN DESKTOP, PHOTO-REALISTIC VIRTUAL ENVIRONMENTS

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the Aim of the Project?

This project is being undertaken as part of the requirements for the INFO341 Human-Computer Interaction course and Masters of Science.

The aim of the project is to determine the appropriateness of heuristics as a usability evaluation for desktop, photo-realistic and panoramic Virtual Environments (VE).

What Type of Participants are being sought?

Participants must be a student of INFO341 Human-Computer Interaction course or associated with members of the University of Otago.

Participants must not be familiar with the use and physical location (and relative vicinity) of the desktop, photo-realistic, panoramic virtual environment.

People who are in one or more of the categories listed below will not be able to participate in the project.

- Those with prior experience with virtual environments.
- Those who are familiar with the location that is being used to model the virtual environment.

What will Participants be Asked to Do?

Should you agree to take part in this project, you will be asked to:

- Provide some information about yourself (gender, age group, familiarity with the location).

- Perform a list of tasks to the best of your abilities using one of the pre-selected VE from the World Wide Web (WWW) while verbalizing your thoughts (think-aloud) as you use the VE system. You will be asked to explore, navigate and search within the VE.

- Conduct, record and collate results from a Heuristic Evaluation using one of the pre-selected VE from the World Wide Web (WWW).

- Participate in answering any questions that may arise during and after the experiment to the best of your abilities.

The process will take no longer than two, one and a half hour sessions during which:

- You may decline to answer any questions or perform any tasks without disadvantage to yourself.
- You will not experience no physical or psychological discomfort.
Appendix B: Ethical Approval

- You may decide not to take any further part in the project without any disadvantage to yourself of any kind.
- You will gain insightful knowledge about think-aloud protocols and usability heuristic evaluations.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind.

Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?

Data collected will include any issues that may arise when using and navigating within the virtual environment. This also includes time taken to perform tasks, any issues that may arise during the use of the system and collated results from the heuristic evaluation. A digital video and still camera will be used to record the participant’s activities as they use the system for later analysis. Any open question interviews that might arise during the activities where the precise nature of the questions which will be asked have not been determined in advance, but will depend on the way in which the interview develops will also be recorded using the digital video camera. In the event that the line of questioning develops in such a way that the participant feels hesitant or uncomfortable, the participant may decline to answer any particular question(s) and/or withdraw from the project without any disadvantage of any kind. Participants will be asked statistical questions (such as age, gender and familiarity with the location) and answers will be recorded for background purposes.

Results of this project may be published but any data included will in no way be linked to any specific participant. The participants’ identities will be protected by not assigning or including any identifiable names. Personal data will be aggregated to ensure that they are not traceable and that no individual can be identified particularly in case(s) of publication. Any statistical data and information collected during the research will be confidential and anonymous.

Data will be stored securely and only accessible to the supervisor, Rochelle Villanueva, Dr. William Wong, and the members of the INFO341 Human-Computer Interaction class. The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University’s research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

You are most welcome to request a copy of the results of the project should you wish.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future. please feel free to contact either:-

Rochelle A Villanueva
Department of Information Science
University Telephone Number: 479 8386
or
Dr. B. L. William Wong
Department of Information Science
University Telephone Number: 479 8322
This project involves an open-questioning technique where the precise nature of the questions which will be asked have not been determined in advance, but will depend on the way in which the interview develops. Consequently, although the University of Otago Human Ethics Committee is aware of the general areas to be explored in the interview, the Committee has not been able to review the precise questions to be used.

In the event that the line of questioning does develop in such a way that you feel hesitant or uncomfortable you are reminded of your right to decline to answer any particular question(s) and also that you may withdraw from the project at any stage without any disadvantage to yourself of any kind.
APPROPRIATENESS OF HEURISTIC EVALUATION IN DESKTOP, PHOTO-REALISTIC VIRTUAL ENVIRONMENTS

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. My participation in the project is entirely voluntary;
2. I will participate and undertake the project tasks to the best of my abilities;
3. I am free to withdraw from the project at any time without any disadvantage;
4. The data video tapes will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed;
5. I will participate in answering any interview questions that the researcher may ask or arise during the course of the activities to the best of my understanding. I understand I could decline to answer any questions without any disadvantage;
6. I will not experience any physical or psychological discomfort;
7. The results of the project may be published but my anonymity will be preserved.

I agree to take part in this project.

..................................................................................  .............................................................................
(Signature of participant)  (Date)

Note:

"This project involves an open-questioning technique where the precise nature of the questions which will be asked have not been determined in advance, but will depend on the way in which the interview develops and that in the event that the line of questioning develops in such a way that I feel hesitant or uncomfortable I may decline to answer any particular question(s) and/or may withdraw from the project without any disadvantage of any kind."
This project involves an open-questioning technique where the precise nature of the questions which will be asked have not been determined in advance, but will depend on the way in which the interview develops. Consequently, although the Head of Department is aware of the general areas to be explored in the interview, the Head of Department has not been able to review the precise questions to be used.

Areas such as:

- Statistical Data (such as age, gender, familiarity with the locations)
- Interactions with Virtual Environments including content of displayed information and its presentation to intuitively show what behavior, consequently action(s) can be performed within the environment (such as navigation, manipulation of objects etc).
## APPROPRIATENESS OF HEURISTIC EVALUATION IN DESKTOP, PHOTO-REALISTIC VIRTUAL ENVIRONMENTS

### SAMPLE PERSONAL DETAILS COLLECTION FORM (RESEARCHER ONLY)

<table>
<thead>
<tr>
<th>Code/Value</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
<th>Participant 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (1 = Male, 2 = Female)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Group: (1 = 18-24, 2 = 25-30, 3 = 31-40, 4 = 40+)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever been to: (1 = Yes, 2 = No)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Sydney Australia (Sydney Opera House)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Canberra, Australia (Questacon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. United Kingdom (Wroxton Abbey, London)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. British Columbia (Great Bear Forest)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Vienna, Austria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Paris, France (Eiffel Tower/Louvre)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever played any 3D games before?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What was it?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In minutes, how long did you usually play with such a game?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever used a Virtual Reality system before?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 = QTVR or 2 = VRML)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion time for System A (hh:mm:ss)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C: TAP VE Task Sheets
Welcome to the Sydney Opera House, Sydney Australia. We hope that your virtual visit will be a pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the South West Forecourt Home Position. See what a beautiful day it is! Have a look around this spot. Can you see the Sydney Bridge?
   - Imagine seeing this in a bigger view. Make the view of the South West Forecourt bigger.

2. Using the main virtual tour, go to Broadwalk North and have a look there.
   - Tell me three things about the Administration Office.
   - Name the designer that “advocated” Olive Trees in the design of the restaurant.

3. The Concert Hall Auditorium is in Level Three.
   - Locate the Royal Box U and have a look around there.
   - Name the visiting Royal who sat there in listening to Beethoven’s Symphony No 9 in D minor.
   - State the exact date of this Royal visit.
   - Name two seat numbers visible at this area.

4. Have a look at the Concert Hall Auditorium Stalls.
   - Name two other places you can get to from here.

5. Go to the Concert Hall Foyer South.
   - Name the labels written on the three colored box signs by the coffee bar.

6. Return to South West Forecourt Home Position.

   Thank you for visiting the Sydney Opera House.

   Please provide some feedback about this facility.
Sydney Opera House (Sydney, Australia)


Welcome to the Sydney Opera House, Sydney Australia. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the South West Forecourt Home Position. See what a beautiful day it is! Have a look around this spot. Can you see the Sydney Bridge?
   - Imagine seeing this in a bigger view. Can you find out how to make the view of the South West forecourt bigger?

2. Go to the Concert Hall Foyer South.
   - Name the labels written on the three colored box signs by the coffee bar.

3. The Concert Hall Auditorium is in Level Three.
   - Locate the Royal Box U and have a look around there.
   - Name the visiting Royal who sat there in listening to Beethoven’s Symphony No 9 in D minor.
   - State the exact date of this Royal visit.
   - Name two visible seat numbers at this area.

4. Have a look at the Concert Hall Auditorium Stalls.
   - Name two other places you can get to from here.

5. Using the main virtual tour, go to Broadwalk North and have a look there.
   - Tell me three things about the Administration Office.
   - Name the designer that “advocated” Olive Trees in the design of the restaurant.

6. Return to South West Forecourt Home Position.

   Thank you for visiting the Sydney Opera House.

   Please provide some feedback about this facility.
Welcome to the Sydney Opera House, Sydney Australia. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the South West Forecourt Home Position. See what a beautiful day it is! Have a look around this spot. Can you see the Sydney Bridge?

2. The Concert Hall Auditorium is in Level Three. Locate the Royal Box U and have a look around there.
   - Name the visiting Royal who sat there in listening to Beethoven’s Symphony No 9 in D minor.
   - State the exact date of this Royal visit.
   - Name two visible seat numbers at this area.

3. Go to the Concert Hall Foyer South.
   - Name the labels written on the three colored box signs by the coffee bar.

4. Have a look at the Concert Hall Auditorium Stalls.
   - Name two other places you can get to from here.
   - Imagine seeing this in a bigger view. Can you find out how to make the view of the Concert Hall Auditorium Stalls bigger?

5. Return to South West Forecourt Home Position.

6. Using the main virtual tour, go to Broadwalk Ncrtth and have a look there.
   - Tell me three things about the Administration Office.
   - Name the designer that “advocated” Olive Trees in the design of the restaurant.

Thank you for visiting the Sydney Opera House.

Please provide some feedback about this facility.
Welcome to the Questacon, Canberra, Australia. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the Questacon Front Entrance. Have a look here. Find the spinning spiral! Feeling different yet?
   - Imagine seeing this in a bigger view. Can you find out how to make the view of the Questacon Front Entrance bigger?

2. If you figured out how to make the tour bigger and have looked around it, go back to the main virtual tour (the one you started with).
   - Use the main tour to re-locate yourself to the Foyer and have a look there.
   - Tell me three of the possible four, interesting objects you can see from the Foyer using the virtual tour.

3. Somewhere in the Foyer there is a machine called a “Gravitram”. Tell me, as best you can, how it works.

4. Go to the Science Court using the main virtual tour. Look around. My what a warm place to be!
   - Find the Granite Ball. State, in kilograms, the weight of the granite ball.

5. Find the Questacon Prototype Area. Go there and have a look. Tell me which level it’s located

6. Go to the South Roof outside.
   - Name five other views you can see from this location.

7. Return to Foyer.
   - From here, find the location where you can experience earthquakes, lighting and a cyclone. Tell me what level can I find it.
   - Go back to the Questacon Front Entrance

Thank you for visiting the Questacon.

Please provide some feedback about this facility.
Welcome to the Questacon, Canberra, Australia. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the Questacon Front Entrance. Have a look here. Find the spinning spiral! Feeling different yet?

2. Use the virtual tour itself to re-locate yourself to the Foyer and have a look there.
   - Tell me three of the possible four, interesting objects you can see from the Foyer using the virtual tour.

3. Somewhere in the Foyer there is a machine called a “Gravitram”. Tell me, as best you can, how it works.

4. Go to the Science Court using the main virtual tour. Look around. My what a warm place to be!
   - Find the Granite Ball. State, in kilograms, the weight of the granite ball.
   - Imagine seeing this in a bigger view. Can you find out how to make the view of the Science Court bigger? If you figured out how to make the tour bigger and have looked around it

5. If you have NOT figured out how to make the tour bigger, use the virtual tour itself to go back inside the Questacon Café.
   - There is an interesting object that is hanging from the ceiling called a Cam Wave. Tell me as best you can, what does it do?

6. Find the Questacon Prototype Area. Go there and have a look. Tell me which level it’s located

7. Go to the South Roof outside.
   - Name five other views you can see from this location.

8. Return to Foyer.
   - From here, find the location where you can experience earthquakes, lighting and a cyclone. Tell me what level can I find it.
   - Go back to the Questacon Front Entrance

Thank you for visiting the Questacon.

Please provide some feedback about this facility.
Welcome to the Questacon, Canberra, Australia. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Welcome! Start at the Questacon Front Entrance. Have a look here. Find the spinning spiral! Feeling different yet?

2. Use the virtual tour itself to re-locate yourself to the Foyer and have a look there.
   - Tell me three of the possible four, interesting objects you can see from the Foyer using the virtual tour.

3. Go to the Science Court using the main virtual tour. Look around. My what a warm place to be!
   - Find the Granite Ball. State, in kilograms, the weight of the granite ball.

4. Use the virtual tour itself to go back inside the Questacon Café.
   - There is an interesting object that is hanging from the ceiling called a Cam Wave. Tell me as best you can, what does it do?

5. Find the Questacon Prototype Area. Go there and have a look. Tell me which level it’s located.

6. Somewhere in the Foyer there is a machine called a “Gravitram”. Tell me, as best you can, how it works.

7. Go to the South Roof outside.
   - Imagine seeing this in a bigger view. Can you find out how to make the view of the South Roof bigger? If you figured out how to make the tour bigger and have looked around it. Otherwise,
   - Name five other views you can see from this location.

8. Return to Foyer.
   - From here, find the location where you can experience earthquakes, lighting and a cyclone. Tell me what level can I find it.
   - Go back to the Questacon Front Entrance
Welcome to Wroxton Abbey. We hope that your virtual visit will be a pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Start your virtual tour in the Driveway. Have a look around. My what massive grounds it covers!
   - “Approach” the Main Entrance and have a look around.

2. Go to the Abbey’s Main Entrance.
   - Name some of the other locations you can go from here.

3. In the Entrance Hallway, name the one or both of the flags that are hanging on the ceiling/wall.

4. Look around the Great Hall.
   - Count the number of light bulbs attached to chandelier hanging above the Great Hall.

5. Count the number of chairs in the Wroxton Chapel. How many were they again?

6. Name the century that the Augustinian priory foundation was constructed in.

7. From the Main Driveway, have a look at the North Side of the Abbey.

Thank you for visiting the Wroxton Abbey.

Please provide some feedback about this facility.
The Wroxton Abbey (England)
http://www.wroxtonabbey.org/index1.html

Welcome to Wroxton Abbey. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Start your virtual tour in the Driveway. Have a look around. My what massive grounds it covers!
   - “Approach” the Main Entrance and have a look around.

2. From the Main Driveway, have a look at the North Side of the Abbey.

3. Go to the Abbey’s Main Entrance.
   - Name some of the other locations you can go from here.

4. In the Entrance Hallway, name the one or both of the flags that are hanging on the ceiling/wall.

5. Look around the Great Hall.
   - Count the number of lights bulbs attached to chandelier hanging above the Great Hall.

6. Name the century that the Augustinian priory foundation was constructed in.

7. Count the number of chairs in the Wroxton Chapel. How many were they again?

Thank you for visiting the Wroxton Abbey.

Please provide some feedback about this facility.
The Wroxton Abbey (England)
http://www.wroxtonabbey.org/index1.html

Welcome to Wroxton Abbey. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

1. Start your virtual tour in the Driveway. Have a look around. My what massive grounds it covers!
   - From the Main Driveway, go and have a look at the Wroxton Village.

2. Return to the Wroxton Abbey. “Approach” the Main Entrance and have a look around.
   - Name some of the other locations you can go from here.

3. Go to the Abbey’s Main Entrance.
   - From here, find your way to the Wroxton Chapel. Once there, count the number of chairs in the.

4. Look around the Great Hall.
   - Count the number of lights bulbs attached to chandelier hanging above the Great Hall.

5. From the Entrance Hallway, name the flags that are hanging on the ceiling/wall.

6. Name the century that the Augustinian priory foundation was constructed in.

Thank you for visiting the Wroxton Abbey.

Please provide some feedback about this facility.
Richard Strauss Villa in Garmisch

http://www.richardstrauss.at/html_e/02_privatlOfs_index.html

Welcome to a private virtual viewing of the life of Richard Strauss. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

   - State the year that the Strauss’ took residence here.

2. Explore the Hall.
   - There is an interesting mask hanging by table by the window, what do you think it could be?

3. Name the room in the house that has a baby grand piano.

4. From the Kitchen, name other parts of the house that you can go to.

5. In the Library, count the number of single chairs in the room.

6. Name Strauss’ favorite card game often played by the Bay Window.

7. Explore the Study.
   - From here, using the virtual reality itself, find your way back to the start – outside the house: Façade.

Thank you for visiting the Richard Strauss Villa in Garmisch.

Please provide some feedback about this facility.
Welcome to a private virtual viewing of the life of Richard Strauss. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

   - State the year that the Strauss’ took residence here.

2. Explore the Hall.
   - There is an interesting mask hanging by the stained glass window above the window, give your impression of this object.

3. Name Strauss’ favorite card game often played by the Bay Window.

4. From the Dining Room, name other parts of the house that you can go to.

5. Name the room in the house that has a baby grand piano.

6. In the Library, count the number of single chairs in the room.

7. Explore the Study.
   - From here, using the virtual reality itself, find your way back to the start – outside the house: Façade.

Thank you for visiting the Richard Strauss Villa in Garmisch.

Please provide some feedback about this facility.
Welcome to a private virtual viewing of the life of Richard Strauss. We hope that your virtual visit will be pleasant one. There are lots to see. Below are some “Not to be Missed” locations. To make your virtual visit more enjoyable and more informative, some points of interest that you may like to have a look at are the following:

   - State the year that the Strauss’ took residence here.

2. Explore the Hall.
   - There is an interesting mask hanging on the wall beside the stained glass window above the table with all the potted plants. Give your impression of this object.

3. In the Library, count the number of single chairs in the room.

4. Name Strauss’ favorite card game often played by the Bay Window.

5. From the Dining Room, name other parts of the house that you can go to.

6. Name the room in the house that has a baby grand piano.

7. Explore the Study.
   - From here, using the virtual reality itself, find your way back to the start – outside the house: Façade.

**Thank you for visiting the Richard Strauss Villa in Garmisch.**

**Please provide some feedback about this facility.**
Appendix D: Data Collection Sheet
### Sample of Personal Details Collection Form (Researcher Only)

<table>
<thead>
<tr>
<th>Code/Value</th>
<th>Participant 1</th>
<th>Participant 2</th>
<th>Participant 3</th>
<th>Participant 4</th>
<th>Participant 5</th>
<th>Participant 6</th>
<th>Participant 7</th>
<th>Participant 8</th>
<th>Participant 9</th>
<th>Participant 10</th>
<th>Participant 11</th>
<th>Participant 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender: Male (1), Female (2)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Age Group: 18-24(1), 25-30(2), 31-40(3), 40+(4)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Game Use: Have you ever played 3D games before? No (0), Yes (1)</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Specific Games: What were they? Not Applicable (0)</td>
<td>Fallen Saga, Sim City</td>
<td>0</td>
<td>Ratic, DOOM, Quake, Jedi Knight</td>
<td>0</td>
<td>0</td>
<td>DOOM, Sim City, Quake, Nuke'em Duke'em</td>
<td>DOOM, Sports games like Rugby and Soccer</td>
<td>0</td>
<td>James Bond, Sports Games like Soccer</td>
<td>Soccer Game, Fighting Game, Car Racing, Shooting</td>
<td>Quake</td>
<td>Doom, Nuke'em Duke'em</td>
</tr>
<tr>
<td>Game Playing Duration: In minutes, how long do you usually play in one sitting? Not Applicable (0), &lt;30 minutes (1), 31-60 minutes (2), &gt;61 minutes (3)</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>VR Use: Have you ever used a VR system before? No (0), Yes (1)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VR Type: What type of VR did you use? Not Applicable (0), Immersive (1), Augmented (2), Desktop (3)</td>
<td>0</td>
<td>0</td>
<td>0, 3</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>System Assigned: Sydney Opera House (1), Questacon, Canberra Australia (2), Wroxton Abbey, England (3), Robert Strauss House in Garmisch, Austria (4)</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Familiarity: Have you ever been to either the assigned system before? No (0), Yes (1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Time taken to Explore (mm:ss:tt) - up to 30:00:00 minutes</td>
<td>0:00:00</td>
<td>23:50:00</td>
<td>26:29:19</td>
<td>15:20:00</td>
<td>11:57:20</td>
<td>8:20:10</td>
<td>6:50:12</td>
<td>11:55:32</td>
<td>21:28:43</td>
<td>30:00:00</td>
<td>18:34:37</td>
<td>13:34:29</td>
</tr>
<tr>
<td>DV Tape (LP) Start Exploration (h:mm:ss)</td>
<td>0:10:36</td>
<td>0:13:19</td>
<td>57:50:00</td>
<td>0:00:03</td>
<td>0:24:52</td>
<td>0:00:05</td>
<td>0:35:40</td>
<td>1:33:44</td>
<td>0:35:44</td>
<td>1:07:31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DV Tape (LP) End Interview (h:mm:ss)</td>
<td>0:08:54</td>
<td>57:22:08</td>
<td>1:33:45</td>
<td>0:24:51</td>
<td>1:33:44</td>
<td>0:35:44</td>
<td>1:07:31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix E: TAP and Interview Questions
Think Aloud Questions
1. What are you thinking now?
2. What sort of message were you expecting?
3. Was that the response you were expecting?
4. Why did you think that happened?
5. What do you think will happen if you did it like that?
6. Is that what you expected to happen?

Interview Questions
1. What did you think of the application – the VR system?
2. What did you liked most of the system?
3. What did you like the least of the system? How do you think it can be changed?
4. If given the opportunity, would you like to visit the site physically and personally? Why?
5. What did you think about the experiment and the way that it was conducted?
6. What did you think about the tasks?
7. Can I please take your picture?
Appendix F: Usability Heuristic Evaluation Equipment
The following section describes the equipment used in the Usability Heuristic Evaluation.

The usability evaluators conducted heuristic evaluations using two different platforms: Macintosh and PC. Each one is described in detail below.

- **Macintosh environment** – The participants used Macintosh G4s and e-Macs. The following section describes each machine specification.
  
  **Macintosh G4s**
  - 400Mhz PowerPC G4, 512 Mb RAM
  - Standard Dark Grey Mac Keyboard, 3 Button USB Mouse (no scrollable wheel)
  - Apple Internal Speakers
  - Software Versions: QuickTime 6.1, Internet Explorer 5.2, Netscape 7.02, Office X for Mac

  **eMacs**
  - 700Mhz PowerPC G4, 512 Mb RAM
  - Standard White/Transparent Mac Keyboard and Mouse (no scrollable wheel)
  - Apple Internal Speakers
  - Software Versions: QuickTime 6.1, Internet Explorer 5.2, Netscape 7.02, Office X for Mac

- **PC Dell OptiPlex** – The participants also used PC Dell machines. The following section describes each machine specification.
  
  **Dell Optiplex GX115s**
  - 933Mhz Intel P3, 512 Mb RAM
  - Dell PS/2 Keyboard, Microsoft PS/2 Intellimouse (with scrollable wheel)
  - Dell Internal Speakers
  - Software Versions: QuickTime 6.3, Internet Explorer 6, Netscape 7.02, Office 2000

  **Dell Optiplex GX115**
  - 933Mhz Intel P3, 256 Mb RAM
  - Dell PS/2 Keyboard, Microsoft PS/2 Intellimouse (with scrollable wheel)
  - Dell Internal Speakers
  - Software Versions: QuickTime 6.3, Internet Explorer 6, Netscape 7.02, Office 2000

  **Dell Optiplex GX110**
  - 733Mhz Intel P3, 512 Mb RAM
  - Dell PS/2 Keyboard, Microsoft PS/2 Intellimouse (with scrollable wheel)
  - Dell Internal Speakers
  - Software Versions: QuickTime 6.3, Internet Explorer 6, Netscape 7.02, Office 2000
Appendix G and H: Emergent Themes Analysis of the Heuristic Evaluation and Think-Aloud Protocol Data CD
<table>
<thead>
<tr>
<th>Usability Problems</th>
<th>Frequency</th>
<th>Criticality</th>
<th>Severity</th>
<th>Sub-broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard to find how to make screen bigger</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Hidden System Functionality - Making the screen [VR Window] bigger within the system is NOT obvious to the user</td>
</tr>
<tr>
<td>Not all arrows tell you where you are going</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Inconsistency in the design</td>
</tr>
<tr>
<td>No Back function (back to where you were not back to start)</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>There is no quick UNDO of actions.</td>
</tr>
<tr>
<td>Functionality hidden</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Lost the map via “rewind” don’t know how to get map back</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>There is no quick UNDO of actions.</td>
</tr>
<tr>
<td>Nothing to indicate to move the mouse to get left, right. No directional info (North, south, east, west)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>Hidden System Functionality - Navigating within the system is NOT obvious to the user</td>
</tr>
<tr>
<td>Can only look left to right not up and down</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>Limited Movement and FOV</td>
</tr>
<tr>
<td>When click on an option no feedback which can lead to multiple clicks and system crashing</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>Lack of system state feedback</td>
</tr>
<tr>
<td>Hard to know where your current location is</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>Difficult to know the user's current location</td>
</tr>
<tr>
<td>Don’t what is available without random exploration</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>Difficult to know what options are available such as locations to view without exploration</td>
</tr>
<tr>
<td>2 ways to navigate but must use help or find out by trial and error</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>Hidden System Functionality - Navigating within the system is NOT obvious to the user</td>
</tr>
<tr>
<td>Not clear what “i” means</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>Jargon and symbols do not mean anything to the user</td>
</tr>
<tr>
<td>Jargon used</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Usability Problems</td>
<td>Themes</td>
<td>Sub-broad Themes</td>
<td>Broad Themes</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>Not clear what &quot;i&quot; means</td>
<td>Jargon and symbols do not mean anything to the user</td>
<td>Jargon and symbols do not mean anything to the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jargon used</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can only look left to right not up and down</td>
<td>Limited Freedom and Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 ways to navigate but must use help or find out by trial and error</td>
<td>Hidden System Functionality - Navigating within the system is NOT obvious to the user</td>
<td>Hidden System Functionality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nothing to indicate to move the mouse to get left, right. No directional info</td>
<td>Hidden System Functionality - Navigating within the system is NOT obvious to the user</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard to find how to make screen bigger</td>
<td>Hidden System Functionality - Making the screen [VR Window] bigger within the system is NOT obvious to the user</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lost the map via &quot;rewind&quot; don’t know how to get map back</td>
<td>There is no quick UNDO of actions.</td>
<td>There is no quick UNDO of actions available to the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Back function (back to where you were not back to start)</td>
<td>There is no quick UNDO of actions.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When click on an option no feedback which can lead to multiple clicks and system crashing</td>
<td>Lack of system state feedback</td>
<td>Lack of system state feedback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Don’t not what is available without random exploration</td>
<td>Difficult to know what options are available such as locations to view without exploration</td>
<td>Difficult to know what options are available such as locations to view without exploration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard to know where your current location is</td>
<td>Difficult to know the user’s current location</td>
<td>Difficult to know the user’s current location</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Appearance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Functionality</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interaction</td>
<td></td>
</tr>
</tbody>
</table>
### Questacon Science Center: Deriving Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>Usability Problems</th>
<th>Frequency</th>
<th>Criticality</th>
<th>Severity</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a spelling mistake.</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>Spelling Mistake: System presentation</td>
</tr>
<tr>
<td>Once you point the mouse whether on left or right hand side, and then move the</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>User expectation: The VE system should behave in a certain manner</td>
</tr>
<tr>
<td>mouse away from the image area, the image will continue rotating.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How can a user identify which way is North, South, etc? System feedback about</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>Lack of system state feedback: Spatial location of the user.</td>
</tr>
<tr>
<td>location</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The level map does not tell what we can see inside the level</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>Map Levels: Options are hidden from the user</td>
</tr>
<tr>
<td>Some windows have a close button and the other has X rather than close button</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>Close Button: Inconsistency in design - option is hidden from the user</td>
</tr>
<tr>
<td>The close button in the bottom is not visible</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Usability Problem</td>
<td>Themes</td>
<td>Sub-broad Themes</td>
<td>Broad Themes</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------</td>
<td>------------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>How can a user identify which way is North, South, etc? System feedback about location</td>
<td>Lack of system state feedback: Spatial location of the user.</td>
<td>Difficult to know the user's current location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The level map does not tell what we can see inside the level</td>
<td>Map Levels: Options are hidden from the user</td>
<td>Navigational aid - options from the Map is hidden</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once you point the mouse whether on left or right hand side, and then move the mouse away from the image area, the image will continue rotating.</td>
<td>User expectation: The VE system should behave in a certain manner</td>
<td>User expectation was not met. The user was expecting real world conventions to be applicable in the VE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some windows have a close button and the other has X rather than close button</td>
<td>Close Button: Inconsistency in design - option is hidden from the user</td>
<td>Interaction Objects Functions are hidden</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The close button in the bottom is not visible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is a spelling mistake.</td>
<td>Spelling Mistake: System presentation</td>
<td>VR Presentation needs to be improved.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Questacon Science Center: Deriving Broad Themes from Group Heuristic Results**

**Part 4**
## Wroxton Abbey: Deriving Sub-broad Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>Usability Problems</th>
<th>Frequency</th>
<th>Criticality</th>
<th>Severity</th>
<th>Sub-broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a facility for help on this page (Instructions), however it is not laid out well, and introduces ambiguities.</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>Help provided is not clear, the information does not make sense to the user.</td>
</tr>
<tr>
<td>Within the VR, there is no help facility provided, and very limited documentation.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Help and documentation about the system is limited.</td>
</tr>
<tr>
<td>Cross-platform transparency is not evident. For example, when the user drags on the VR to navigate around, it can be expected that this will act as ‘pulling’ the VR around, in a similar fashion to the way in which Adobe Acrobat Reader works. However, the VR moves in the opposite direction.</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>Conventions in the real world should apply here, user expectation is not met.</td>
</tr>
<tr>
<td>There is no differentiation between experienced and inexperienced users.</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>Unappealing and convoluted text, VR Presentation needs to be improved.</td>
</tr>
<tr>
<td>The entry page is dull, with a phenomenal amount of text, in relation to the simple purpose of the page.</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>There is a lack of consistency in design, The user has limited Field of View (FoV) as the navigation only allows left and right only movement.</td>
</tr>
<tr>
<td>Some areas of the VR allow the user to look up/down and right around, but other areas (such as outside) limit navigation to left and right only.</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>Clicking on some hotspots takes the user to a screen containing a series of photos; exiting the VR, while others navigate to a different location, remaining within the VR.</td>
</tr>
<tr>
<td>The link to enter the VR is unclear, and not what the user would think of conceptually – the user thinks they are visiting an Abbey – not a footpath.</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>There is lack of consistency in object functionality presented, user expectation is not met.</td>
</tr>
<tr>
<td>Although the map indicated where you are within the VR with an X, it does not communicate specifically the name of the location.</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>System functionality is unclear due to a poor metaphor being used.</td>
</tr>
<tr>
<td>Techniques required to navigate have to be remembered, as help for this is only available from the Entry Page, not within the VR itself.</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>The map provided only presents limited amount of information, A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
</tr>
<tr>
<td>The hotspots are of such a big size, that unexpected regions of the VR are included in them. For example, clicking on the carpet of the Entrance Hallway, will take you to the Great Hall. This can leave the user confused as to why it happened.</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>Location and size of the hotspots, user expectation is not met leading to confusion.</td>
</tr>
<tr>
<td>Due to the large size of the hotspots, unexpected regions of the VR are included in them. For example, clicking on the carpet of the Entrance Hallway, will take you to the Great Hall. This can leave the user confused as to why it happened.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>System functionality is unclear due to a poor metaphor being used. There is also a lack of system state feedback as to why HOTKEYS were not working.</td>
</tr>
<tr>
<td>When the user attempts to use the hotkeys, the mouse pointer must be within the VR (although this was not communicated). If the mouse pointer was not within the VR, there was nothing to indicate why the hotkeys were not working.</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>There is a lack of system state feedback as to what is currently happening with the system e.g. when LOADING the VE and only a GRID is showing.</td>
</tr>
<tr>
<td>When navigating to a new place, the virtual reality grid shows, however there is nothing to indicate to the uninitiated what is happening – whether the system is processing, or if it has halted.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met.</td>
</tr>
<tr>
<td>The user has limited access certain places. In the real world, when you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when returning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village).</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met which will lead to user confusion of their spatial location and their options.</td>
</tr>
<tr>
<td>When you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when turning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village). This can lead to errors by confusing the user as to where they are, what direction they are heading in, and where a hotspot will lead to.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>The VR provides no user control and freedom. It forces you to navigate to certain places, in a system-specified order.</td>
</tr>
<tr>
<td>In the real world, when you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when turning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village).</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>The user is limited in terms of movement as they can only access certain places.</td>
</tr>
<tr>
<td>The VR offers little flexibility in the way in which the user navigates around the system. It forces you to navigate to certain places, in a system-specified order.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>The user is limited in terms of movement as they can only access certain places.</td>
</tr>
<tr>
<td>The window containing the VR and additional information is laid out on the page in a fashion such that it is not aesthetically balanced. The VR is on the left, with a great length of text and the map on the right. The map is sometimes pushed out of sight, due to the length of the text, resulting in frustration when wishing to compare the VR with the map.</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Unappealing layout and presentation of the VR and the related text, VR Presentation could be improved. Map location/presentation is inconsistent as there are varying lengths of text.</td>
</tr>
</tbody>
</table>
| For each location in the VR, the position of the related map moves, to accommodate for the amount of associated text, resulting in inconsistent positioning. | 2         | 4           | 4        | }
### Wroxton Abbey: Deriving Broad Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>Usability Problem</th>
<th>Themes</th>
<th>Sub-broad themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a facility for help on this page (‘Instructions’), however it is not</td>
<td>Help provided is not clear, the information does not make sense to</td>
<td>Help and system documentation is limited, inconsistent in location and unclear</td>
<td></td>
</tr>
<tr>
<td>laid out well, and introduces ambiguities.</td>
<td>the user.</td>
<td>that it affects how the user uses the system.</td>
<td></td>
</tr>
<tr>
<td>Within the VR, there is no help facility provided, and very limited documentation.</td>
<td>Help and documentation about the system is limited.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Techniques required to navigate have to be remembered, as help for this is only</td>
<td>Navigating within the environment need to be remembered by the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>available from the Entry Page, not within the VR itself.</td>
<td>due to the inconsistent VR presentation design - user Memory Load(?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clicking on some hotspots takes the user to a screen containing a series of</td>
<td>There is lack of consistency in object functionality presented,</td>
<td>There is lack of consistency in object functionality presented.</td>
<td></td>
</tr>
<tr>
<td>photos; exiting the VR, while others navigate to a different location, remaining</td>
<td>user expectation is not met.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>within the VR.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When the user attempts to use the hotkeys, the mouse pointer must be within the</td>
<td>System functionality is unclear due to a poor metaphor being used.</td>
<td>System functionality is hidden (due to a poor metaphor).</td>
<td></td>
</tr>
<tr>
<td>VR (although this was not communicated). If the mouse pointer was not within the</td>
<td>There is also a lack of system state feedback as to why HOTKEYS were</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR, there was nothing to indicate why the hotkeys were not working.</td>
<td>not working.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The link to enter the VR is unclear, and not what the user would think of</td>
<td>System functionality is unclear due to a poor metaphor being used.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>conceptually – the user thinks they are visiting an Abbey – not a footpath.</td>
<td>There is a lack of system state feedback as to what is currently</td>
<td>No system state feedback provided to the user.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>happening with the system e.g. when LOADING the VE and only a GRID</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>is showing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The VR provides no user control and freedom. It forces you go navigate to</td>
<td>The user is limited in terms of movement as they can only access</td>
<td>Only limited movement available in the VE.</td>
<td></td>
</tr>
<tr>
<td>certain places, in a system-specified order.</td>
<td>certain places.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The VR offers little flexibility in the way in which the user navigates around</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the system. It forces you go navigate to certain places, in a system-specified</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>order.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some areas of the VR allow the user to look up/down and right around, but other</td>
<td>There is a lack of consistency in design, The user has limited Field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>areas (such as outside) limit navigation to left and right only.</td>
<td>of View (FoV) as the navigation only allows left and right only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is no differentiation between experienced and inexperienced users.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The entry page is dull, with a phenomenal amount of text, in relation to the</td>
<td>A clear distinction between novice and experienced users is needed.</td>
<td>A clear distinction between novice and experienced users is needed.</td>
<td></td>
</tr>
<tr>
<td>simple purpose of the page.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The window containing the VR and additional information is laid out on the page</td>
<td>Unappealing and convoluted text, VR Presentation needs to be</td>
<td>VR Presentation needs to be improved.</td>
<td></td>
</tr>
<tr>
<td>in a fashion such that it is not aesthetically balanced. The VR is on the left,</td>
<td>improved.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with a great length of text and the map on the right. The map is sometimes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pushed out of sight, due to the length of the text, resulting in frustration when</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wishing to compare the VR with the map.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Wroxton Abbey: Deriving Broad Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>Usability Problem</th>
<th>Themes</th>
<th>Sub-broad themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>For each location in the VR, the position of the related map moves, to accommodate for the amount of associated text, resulting in inconsistent positioning.</td>
<td>Location and size of the hotspots, user expectation is not met leading to confusion.</td>
<td>Location and size of the hotspots, user expectation is not met leading to confusion.</td>
<td></td>
</tr>
<tr>
<td>The hotspots are of such a big size, that unexpected regions of the VR are included in them. For example, clicking on the carpet of the Entrance Hallway, will take you to the Great Hall. This can leave the user confused as to why it happened.</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
<td>The user's FoV does not match as that of the real world</td>
<td></td>
</tr>
<tr>
<td>Due to the large size of the hotspots, unexpected regions of the VR are included in them. For example, clicking on the carpet of the Entrance Hallway, will take you to the Great Hall. This can leave the user confused as to why it happened.</td>
<td>Location and size of the hotspots, user expectation is not met leading to confusion.</td>
<td>Location and size of the hotspots, user expectation is not met leading to confusion.</td>
<td></td>
</tr>
<tr>
<td>In the real world, when you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when returning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village).</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
<td>The user's FoV does not match as that of the real world</td>
<td></td>
</tr>
<tr>
<td>When you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when turning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village).</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
<td>The user's FoV does not match as that of the real world</td>
<td></td>
</tr>
<tr>
<td>In the real world, when you walk from one destination to another, you would expect to be facing the ‘ahead’ direction when you arrive at the destination, however this is not the case. For example, when turning from the Wroxton Village to the Abbey, you are left facing the direction from which you’ve come (Wroxton Village).</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
<td>The user's FoV does not match as that of the real world</td>
<td></td>
</tr>
<tr>
<td>Although the map indicated where you are within the VR with an X, it does not communicate specifically the name of the location.</td>
<td>The map provided only presents limited amount of information, A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td></td>
</tr>
<tr>
<td>Cross-platform transparency is not evident. For example, when the user drags on the VR to navigate around, it can be expected that this will act as ‘pulling’ the VR around, in a similar fashion to the way in which Adobe Acrobat Reader works. However, the VR moves in the opposite direction.</td>
<td>Conventions in the real world should apply here, user expectation is not met</td>
<td>User expectation was not met. The user was expecting real world conventions to be applicable in the VE</td>
<td></td>
</tr>
</tbody>
</table>

---

1. **Appendix G: Emergent Themes Analysis of the Heuristic Evaluation Data**
2. **Usability Problem**
3. **Themes**
4. **Sub-broad themes**
5. **Broad Themes**
6. **Appearance**
7. **Interactions**
### Richard Strauss House: Deriving Sub-broad Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>Usability Problems</th>
<th>Frequency</th>
<th>Criticality</th>
<th>Severity</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Don’t face correct direction when exiting a room</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
</tr>
<tr>
<td>Can’t move forward, can’t examine objects</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>User has limited movement that they cannot examine objects within the VE closer - zoom (?)</td>
</tr>
<tr>
<td>Only PC: Help and exit (close window) not available, Map not visible either</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>Cross platform availability is lacking, inconsistency in VR presentation design.</td>
</tr>
<tr>
<td>Scrolling to fast, can’t read all the text, need to scroll</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Interaction objects (SCROLL BARS) were not behaving as it’s supposed to</td>
</tr>
<tr>
<td>Map don’t tell you where you are or where you can go. Map in Façade (1) don’t map environment, PC: Map covered. Won’t feedback in toolbar</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>The navigational aid provided is limited in that it does not explicitly state the user's current spatial location. The map also does not correspond to the VE environment. There is a lack of system state feedback to the user.</td>
</tr>
<tr>
<td>Toolbar feedback, non-used buttons, not telling you where you are or where to go.</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>There is a lack of consistency in design, The user has limited Field of View (FoV) as the navigation only allows left and right only movement.</td>
</tr>
<tr>
<td>Can’t look up or down, only left or right</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>There is a lack of consistency in design, The user has limited Field of View (FoV) as the navigation only allows left and right only movement. Real world conventions should apply here (such as looking outside a window), location and size of the hotspots, user expectation is not met.</td>
</tr>
<tr>
<td>Can it look around 360°, only 270°, Sun to strong in windows, standing table</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>There is a lack of consistency in design, The user has limited Field of View (FoV) as the navigation only allows left and right only movement. Real world conventions should apply here (such as looking outside a window), location and size of the hotspots, user expectation is not met.</td>
</tr>
<tr>
<td>When loading, no feedback when finished black and white framework/grid shown</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>There is a lack of system state feedback as to what is currently happening with the system e.g. when LOADING the VE and only a GRID is showing.</td>
</tr>
<tr>
<td>Cultural/art history language. No dictionary (hypertext, boxes) available</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>Words and language used does not make sense to the user</td>
</tr>
<tr>
<td>Usability Problems</td>
<td>Themes</td>
<td>Sub-broad Themes</td>
<td>Broad Themes</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Don’t face correct direction when exiting a room</td>
<td>The user FoV is incorrect, real world conventions should apply here, user expectation is not met</td>
<td>Limited FoV and movement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can’t move forward, can’t examine objects</td>
<td>User has limited movement that they cannot examine objects within the VE closer - zoom (?)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can’t look up or down, only left or right</td>
<td>There is a lack of consistency in design. The user has limited Field of View (FoV) as the navigation only allows left and right only movement. Real world conventions should apply here (such as looking outside a window), location and size of the hotspots, user expectation is not met.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can it look around 360°, only 270°, Sun to strong in windows, standing table</td>
<td>There is a lack of consistency in design. The user has limited Field of View (FoV) as the navigation only allows left and right only movement. Real world conventions should apply here (such as looking outside a window), location and size of the hotspots, user expectation is not met.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only PC: Help and exit (close window) not available, Map not visible either</td>
<td>Cross platform availability is lacking, inconsistency in VR presentation design.</td>
<td>Cross platform availability is lacking, inconsistency in VR presentation design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrolling to fast, can’t read all the text, need to scroll</td>
<td>Interaction objects (SCROLL BARS) were not behaving as its supposed to</td>
<td>Interaction Objects Functions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When loading, no feedback when finished black and white framework/grid shown</td>
<td>There is a lack of system state feedback as to what is currently happening with the system e.g. when LOADING the VE and only a GRID is showing.</td>
<td>No system state feedback provided to the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map don’t tell you where you are or where you can go. Map in Façade (1) don’t map environment. PC Map covered. Won’t feedback in toolbar</td>
<td>The navigational aid provided is limited in that it does not explicitly state the user’s current spatial location. The map also does not correspond to the VE environment. There is a lack of system state feedback to the user.</td>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toolbar feedback, non-used buttons, not telling you where you are or where to go.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural/art history language. No dictionary (hypertext, boxes) available</td>
<td>Words and language used does not make sense to the user</td>
<td>Jargon and symbols do not mean anything to the user</td>
<td>Appearance</td>
<td></td>
</tr>
</tbody>
</table>

**Functionality**

**Interactions**

**Appearance**
## Sydney Opera House (SOH) versus Questacon Science Center (QSC): Deriving Broad Themes Group Heuristic Evaluation

<table>
<thead>
<tr>
<th>SOH Broad Themes</th>
<th>QSC Broad Themes</th>
<th>Sub-broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hidden System Functionality</td>
<td>Hidden System Functionality</td>
<td></td>
<td>Functionality</td>
</tr>
<tr>
<td>Lack of system state feedback</td>
<td>Lack of VE System Feedback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limited Movement and FOV</td>
<td>Limited movement and FoV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction Objects Functions are hidden</td>
<td>Functions of interaction objects are hidden from the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is no quick UNDO of actions available to the user</td>
<td>There is no quick UNDO of actions available to the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult to know what options are available such as locations to view without exploration</td>
<td>Exploration of the System is needed by the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult to know the user's current location</td>
<td>Difficult to know the user's current location</td>
<td>Difficult for user's to know their current location</td>
<td>Interaction</td>
</tr>
<tr>
<td>Navigational aid - options from the Map is hidden</td>
<td>Navigational Aid - the map options are hidden from the user</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User expectation was not met. The user was expecting real world conventions to be applicable in the VE</td>
<td>User expectations were not met</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inconsistency in the design</td>
<td>VR Presentation needs to be improved.</td>
<td>VR Presentation needs to be improved.</td>
<td>Appearance</td>
</tr>
<tr>
<td>Jargon and symbols do not mean anything to the user</td>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Wroxton Abbey (WA) versus Richard Strauss House (RSH): Deriving Broad Themes from Group Heuristic Results

<table>
<thead>
<tr>
<th>WA Broad Themes</th>
<th>RSH Broad Themes</th>
<th>Sub-broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No system state feedback provided to the user</td>
<td>No system state feedback provided to the user</td>
<td>Limited VE system feedback</td>
<td></td>
</tr>
<tr>
<td>The user's FoV does not match as that of the real world</td>
<td>Limited FoV and movement</td>
<td>Limited movement and FoV</td>
<td></td>
</tr>
<tr>
<td>Only limited movement available in the VE</td>
<td>Interaction Objects Functions</td>
<td>Functions of interaction objects are hidden from the user</td>
<td></td>
</tr>
<tr>
<td>There is lack of consistency in object functionality presented</td>
<td>Help and system documentation is limited, inconsistent in location and unclear that it affects how the user uses the system.</td>
<td>Limited system help and documentation.</td>
<td></td>
</tr>
<tr>
<td>System functionality is hidden (due to a poor metaphor)</td>
<td>A clear distinction between novice and experienced users is needed.</td>
<td>Lack of Cross-platform availability</td>
<td></td>
</tr>
<tr>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>Cross platform availability is lacking, inconsistency in VR presentation design.</td>
<td>Lack of Cross-platform availability</td>
<td></td>
</tr>
<tr>
<td>User expectation was not met. The user was expecting real world conventions to be applicable in the VE</td>
<td>Jargon and symbols do not mean anything to the user</td>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td></td>
</tr>
<tr>
<td>VR Presentation needs to be improved</td>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Functionality**

**Interactions**

**Appearance**
### Large- versus Small-scale VE system: Deriving Broad Themes from Group Heuristic Evaluation Results

<table>
<thead>
<tr>
<th>Large-scale VE systems</th>
<th>Small-scale VE systems</th>
<th>Sub-broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions of interaction objects are hidden from the user</td>
<td>Functions of interaction objects are hidden from the user</td>
<td>Interaction Object Functionality</td>
<td></td>
</tr>
<tr>
<td>Limited movement and FoV</td>
<td>Limited movement and FoV</td>
<td>Limited Freedom</td>
<td></td>
</tr>
<tr>
<td>Hidden System Functionality</td>
<td>Hidden System Functionality</td>
<td>Hidden System Functionality</td>
<td></td>
</tr>
<tr>
<td>Lack of VE System Feedback</td>
<td>Limited VE system feedback</td>
<td>Lack of VE System Status Feedback</td>
<td></td>
</tr>
<tr>
<td>There is no quick UNDO of actions available to the user</td>
<td>Limited system help and documentation.</td>
<td>Hidden System Functionality</td>
<td></td>
</tr>
<tr>
<td>Lack of Cross-platform availability</td>
<td>A clear distinction between novice and experienced users is needed.</td>
<td>Cross Platform</td>
<td></td>
</tr>
<tr>
<td>Difficult for user's to know their current location</td>
<td>Difficult for user's to know their current location</td>
<td>Difficult for user's to know their current location</td>
<td></td>
</tr>
<tr>
<td>User expectations were not met</td>
<td>User expectations were not met.</td>
<td>User Expectations</td>
<td></td>
</tr>
<tr>
<td>Navigational Aid - the map options are hidden from the user</td>
<td>A complete and clear relationship between the navigational aid (map) and the VR is missing.</td>
<td>Navigational Aids</td>
<td></td>
</tr>
<tr>
<td>Exploration of the System is needed by the user</td>
<td>VR Presentation needs to be improved.</td>
<td>System Exploration</td>
<td></td>
</tr>
<tr>
<td>VR Presentation needs to be improved.</td>
<td>Location and size of hotspots</td>
<td>VE Presentation Comments</td>
<td></td>
</tr>
<tr>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td>Information presented to the user such as words, icons, symbols, it's meaning is not clear</td>
<td>Information Presentation</td>
<td></td>
</tr>
</tbody>
</table>
### SOH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Data

#### P10 - Comments made while mainly about the task

| P10: (0:31:54) - ...Um, and then I want to see one of these one, two, three (rolling over the Map Level links located on the bottom right hand side of the window screen). (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location labels)… |
| P11: (0:15:43) - Okay, actually, to see this map, what does it (rolling over the 3D map) play? I think this tell me about my position inside the house (rolling over the 3D map)? No, No, it's not my position. Oh, Oh... what actually is in this position? I'm not sure where I can find my position here... Trying to find out. |

#### P12 - Comments made while mainly about the task

| P12: (1:32:17) - We took at the "Concert Hall Auditorium Stalls" (clicked on the embedded hotspot (yellow arrow) linking to the Concert Hall Foyer East, panning within the VR). Um, I'm just trying to find out these boxes, but I think I was wrong. By coming here, how can I now, how can I go back to where I came from? (1:31:13) |
| P11: (0:08:53) - Okay. So going to the 1st level to the 2nd level and I don't know how I did that (panning within the VR, rolling over the embedded links) (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location labels)… |

#### P11 - Issues

| P11: (0:14:19) - Panning within the VR, rolling over the embedded links, It doesn't tell me where I am. Okay, (Panning within the VR, rolling over the embedded links) I'm on the 2nd Floor North (also indicated on the Map Level). I must have got there a different way I suppose. So I'm still lost (0:14:37). |

#### Sub-broad Themes

| P11: (0:15:18) - "And I'm not quite sure where I am (panning within the VR and as you pan, yellow arrows and !) For further information appears inside the VR indicating that it is click-able." |

#### P12 - Comments made while mainly about the task

| P12: (0:14:19) - Panning within the VR, rolling over the embedded links (Clicked on the embedded hotspot leading to the Box Stage, but actually clicked on the "i" for information about the Stage). Oops, did it wrong, get rid of that (Clicked Close). (Clicking on an embedded hotspot to lead to the Box Stage). |

#### Issue

| P11: (0:14:19) - So I'm a bit lost (0:14:37). |

#### Sub-broad Themes

| P11: (0:01:18) - "And I'm not quite sure where I am (panning within the VR and as you pan, yellow arrows and !) For further information appears inside the VR indicating that it is click-able." |

#### P11 - Issues

| P11: (0:14:19) - "And I'm not quite sure where I am (panning within the VR and as you pan, yellow arrows and !) For further information appears inside the VR indicating that it is click-able." |

#### Sub-broad Themes

| P12: (0:08:53) - Okay. So going to the 1st level to the 2nd level and I don't know how I did that (panning within the VR, rolling over the embedded links) (Clicked on Map Level One) Okay, that probably shows the first level. And (Panning within the VR) I'm wondering if actually you can see anything? (Rolled over the yellow balls on the 3D map to bring up location labels)… |

#### Issue

| P12: (0:14:19) - Panning within the VR, rolling over the embedded links, It doesn't tell me where I am. Okay, (Panning within the VR, rolling over the embedded links) I'm on the 2nd Floor North (also indicated on the Map Level). I must have got there a different way I suppose. So I'm still lost (0:14:37). |

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#### Issue

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#### Sub-broad Themes

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**Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data**

<table>
<thead>
<tr>
<th>P10</th>
<th>Comments made were mainly about the web</th>
<th>P02</th>
<th>P11</th>
<th>Issue</th>
<th>Sub-broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>P10 (1:23:35) - Because I am forgetting… Now how am I supposed to know this (the 3D map), where is south and north? (1:23:40).</td>
<td>P02 (1:33:33) - Okay, but the one is the yellow balls over the 3D map, it's the label of each of the locations, I'm not sure if I'm confused in, where is this Forecourt place?</td>
<td>P11 (27:12) - I can't remember where it is (27:20) (clicked on an embedded hotspot leading to Home Court Start Position) Here we go.</td>
<td>P11</td>
<td>Issue: User needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.</td>
<td>Sub-broad Themes: The user is unsure whether they have visited this location before or not.</td>
</tr>
<tr>
<td>P10 (0:53:35) - So you how do you know that you've been to this area before or not?</td>
<td>P10 (0:54:23) - We can call up (clicked on the down scroll arrow, image is enlarged in a separate window and centered on the screen),...</td>
<td>P11 (27:20) - ...And there is also a scroll bar, scroll down the page (0:57:39)...</td>
<td>Issue: User needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.</td>
<td>The user does not have a clear mental idea of how the provided navigational aid (Map) relates to the VE they are currently in or have visited.</td>
<td></td>
</tr>
<tr>
<td>P10 (0:57:37) - So how do you know that you've been to this area before or not?</td>
<td>P11 (0:57:00) - ...So you how do you know that you've been to this area before or not?…</td>
<td>P11 (1:23:35 - 1:23:48) - I'm wondering what I was supposed to do (1:23:48).</td>
<td>Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.</td>
<td>The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.</td>
<td></td>
</tr>
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**LACK OF FEEDBACK - SYSTEM STATE**

1. **P11 (0:06:14) - (Panning within the VR, rolling over the embedded links) I have no idea where I am going. (Clicked on an embedded hotspot leading to Podium South East, scrolling within the VR, rolling over the embedded links).**

   Issue: The user is lost (they have not established the link between their position on the map and on the VR and they relate to each other) that they have gone in circles and visited the same place more than twice.

2. **P11 (0:05:03) - (Panning within the VR, rolling over the embedded links, clicked on the embedded hotspot or node to try anything).**

   Issue: The user does not have a clear mental idea of how the provided navigational aid (Map) relates to the VE they are currently in or have visited.

3. **P11 (0:09:34 - 0:09:55) - Where I come from? Uhm, (panning within the VR, rolling over the embedded links).**

   Issue: The user is not able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

4. **P10 (0:06:14) - (Panning within the VR, rolling over the embedded links, clicked on an embedded hotspot leading to the Drama Theater Stage, panning within the VR, rolling over the embedded links).**

   Issue: The user is lost because there is no directional information available such as clear indication on the map provided (orientation) which direction is North, South, East or West.

5. **P11 (0:06:33 - 0:06:53) - I don't know how to find these specific places, it's not clear from here, I know how to find the, I mean the positions, south and north…**

   Issue: The user is not able to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map) without referring to the map.

6. **P10 (1:23:35) - Because I am forgetting… Now how am I supposed to know this (the 3D map), where is south and north? (1:23:40).**

   Issue: The user is not able to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map) without referring to the map.

7. **P11 (0:06:33) - So when I pass on it, suddenly the thing appears, click on it and sometimes it does not come up automatically and I have to wait a little while. So in the first place I'm trying to figure out what are these dots.**

   Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

8. **P11 (0:06:35) - (Panning within the VR, rolling over the embedded links, clicking on the embedded hotspot leading to the Opera Theater Scenery Dock). I ended up going around in a circle.**

   Issue: The user is lost because there is no directional information available such as clear indication on the map provided (orientation) which direction is North, South, East or West.

9. **P10 (0:42:18 - 0:42:28) - Okay. So that's why I am saying to you it's confusing because there is lots of places… Okay, there are lots of views, this is great, this is cool, but I can't memorize actually where is, this is the place. I remember what I want them.**

   Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

10. **P10 (0:57:00) - ...So you how do you know that you've been to this area before or not?…**

    Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

11. **P10 (0:59:59) - ...I'm wondering what I was supposed to do (1:23:48).**

    Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

12. **P10 (0:59:59) - ...And it's loading an animation, loading the Sydney Opera House, the VR system is loading). I'm waiting for it to load.**

    Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.

13. **P10 (1:23:35 - 1:23:48) - I'm wondering what I was supposed to do (1:23:48).**

    Issue: The user needs to be able to remember where they have been and access that location easily - especially when they are selecting search for particular information.
Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

| P10: Comments made were mainly about the web | P11: (1:07:49) - I'm wondering if there's anything, any, any visible seat numbers (closed window). Reading the text again, I can't really tell which. I can't name the two on the "I". I'll go back maybe. I'm missing something here. Umm (re-panning within the VR). How can I get that? (panning within the VR, clicked on an image thumbnail to make it bigger). Okay, it shows that I know how to see the view (?). | Issue: The user does not know what the VE system is doing. There is a lack of feedback to the user especially when loading. |

| Part 3 | P11: (1:07:55) - Click on One (clicked on Map Level Two, new layer on the 3D map appears over the hiding one). Make sure that I know how to see the view (?). | Issue: MAP - when the 3D map is clicked, it is unclear to the user that the view or system state has changed. |

| LOCATION SEARCH | P10: (0:47:29) - Okay, where is the restaurant? (Laugh). Again, from here, I think that from the map it's easier. But the problem is where to find it. Then I have to find the position. | Issue: I don't know how to find these specific places. It's not clear where to find the position. |

| P10: (0:38:36) - Because, for example if I clicked here (clicked on the embedded hotspot, panning). There is no information, clicked on "i" for Stage Managers Desk, reading the text, clicked the close window button, clicked on the embedded hotspot leading to the Concert Hall Assembly Room). Okay, we've moved on to the 2nd floor (map level changes as you move around between levels). Button, clicked on the embedded hotspot leading to the Concert Hall Assembly Room). Okay, we've moved on to the 2nd floor (map level changes as you move around between levels). | Issue: The user does not know what the system state has changed (clicked on something such as an embedded hotspot but does not realize that they are in a different location) nor does the user have ways to find the amount of objects presented to the user at one time? Divided attention? |

| P10: (0:51:55) - I'm trying to figure out where it is. They did not specify where to find it. | Issue: The user is finding it difficult to locate another location using either the map or the embedded hotspots. |

| INFORMATION SEARCH - HELP | P10: (0:27:06) - (Reading the task sheet). "Name two visible seat numbers at this area" (Clicked on an image thumbnail to make it bigger). Okay, it shows that I know how to see the view (?). | Issue: The user is finding it difficult to locate another location using either the map or the embedded hotspots. |

| Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data | Issue: The user is finding it difficult to locate another location using either the map or the embedded hotspots. |

SOH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

Part 3
### Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

| P01 (0:42:01) | What is Commercial Operation? (Clicked on Commercial Operation Link). Okay, reading (the task). I don't understand anything from this (because the thumbnails for the images did not load up), so I go back to the image bank (by clicking on the option above the menu). And I'll just click on one of these images. Right tails and bridges (because window with larger image of the thumbnail) and I'll maximize the picture for nothing, really not special. (Scrolled down the page, clicked on the thumbnail for the Concert Hall East). |
| P02 (1:22:16) | P10 was confused but it is giving me information here. For example here (pointing to the arrow inside the VR) direction of the Forecourt Home Position. P10: I was confused but I'm confused. I think it is confusing. I actually would like to see what kind of information here (clicked on the link, which brought up some kind of production information etc), maybe I will tell me what to do, how to start. |
| P02 (1:04:51) | P10 (1:04:29) - What is Commercial Operation? (Clicked on Commercial Operation Link). Okay, reading (the task). I don't understand anything from this (because the thumbnails for the images did not load up), so I go back to the image bank (by clicking on the option above the menu). And I'll just click on one of these images. Right tails and bridges (because window with larger image of the thumbnail) and I’ll maximize the picture for nothing, really not special. (Scrolled down the page, clicked on the thumbnail for the Concert Hall East). |
| P02 (1:22:16) | P10 was confused but it is giving me information here. For example here (pointing to the arrow inside the VR) direction of the Forecourt Home Position. P10: I was confused but I'm confused. I think it is confusing. I actually would like to see what kind of information here (clicked on the link, which brought up some kind of production information etc), maybe I will tell me what to do, how to start. |
| P02 (0:13:52) | P10 (0:10:31) - What is Commercial Operation? (Clicked on Commercial Operation Link). Okay, reading (the task). I don't understand anything from this (because the thumbnails for the images did not load up), so I go back to the image bank (by clicking on the option above the menu). And I'll just click on one of these images. Right tails and bridges (because window with larger image of the thumbnail) and I’ll maximize the picture for nothing, really not special. (Scrolled down the page, clicked on the thumbnail for the Concert Hall East). |
| P02 (1:22:16) | P10 was confused but it is giving me information here. For example here (pointing to the arrow inside the VR) direction of the Forecourt Home Position. P10: I was confused but I'm confused. I think it is confusing. I actually would like to see what kind of information here (clicked on the link, which brought up some kind of production information etc), maybe I will tell me what to do, how to start. |
| P02 (1:04:51) | P10 (1:04:29) - What is Commercial Operation? (Clicked on Commercial Operation Link). Okay, reading (the task). I don't understand anything from this (because the thumbnails for the images did not load up), so I go back to the image bank (by clicking on the option above the menu). And I'll just click on one of these images. Right tails and bridges (because window with larger image of the thumbnail) and I’ll maximize the picture for nothing, really not special. (Scrolled down the page, clicked on the thumbnail for the Concert Hall East). |
| P02 (1:22:16) | P10 was confused but it is giving me information here. For example here (pointing to the arrow inside the VR) direction of the Forecourt Home Position. P10: I was confused but I'm confused. I think it is confusing. I actually would like to see what kind of information here (clicked on the link, which brought up some kind of production information etc), maybe I will tell me what to do, how to start. |

### Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

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<thead>
<tr>
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<th>Issues</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>The user is looking for additional information about a particular location or object but was not available.</td>
<td>P10 (0:22:05 - 0:24:03) - (Panning around looking for the three colored box signs by the coffee bar, located them). There (clicked on the colored boxes). I can't read them. I'm not sure how to make them closer (panning within the VR, rolling over the hotspots) I think that will take me for far away if I clicked on the embedded arrow leading to the Concert Hall Foyer East). (Right-mouse click, Flash Player 6 pop-up menu appears). Alright, clicked on Zoom in, but I still can't read it. (Reading the task sheet, then looked back at the VR) I'm not going back to it. Rolled over some embedded hotspots, clicked on an embedded hotspot (leaving in Concert Hall Foyer East). I see something here can get me closer to them (colored boxes, panning within the VR). (Right-mouse click, on some embedded hotspots, panning what the boxes small step). I think one (yellow arrow) must point west, one east and maybe one down? I dunno. Is that okay? (In fact the colored boxes step up. Don't click).</td>
<td></td>
</tr>
<tr>
<td>The user does not know how to view a High-Resolution VE.</td>
<td>P10 (1:04:29) - Comments made were mainly about the web P01 P02 P11 Issue Sub-broad Themes:</td>
<td></td>
</tr>
<tr>
<td>Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data</td>
<td>Part 5</td>
<td>Issue: The user clicked on an embedded hotspot but arrived at unexpected node/location. They try something unexpected.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>P10 (0:58:36)</td>
<td>Okay, now, can go to, I'm wondering what is Creditos for?</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
</tr>
<tr>
<td>P10 (0:59:22)</td>
<td>Umm, I'm wondering what is this thing (rolling over the link for high resolution panoramic), it's an icon for a real player. Click on it to see what it does (click on the QuickTime icon).</td>
<td>The functions of interaction objects provided on the VE were not clearly defined.</td>
</tr>
<tr>
<td>P10 (1:04:29)</td>
<td>Tenders, what are tenders? Ah, I'm just reading the information about the tenders, cos I have no idea what is tenders.</td>
<td>The user is presented with information that does not clearly functionally defined is ignored by the user.</td>
</tr>
<tr>
<td>P10 (0:59:23)</td>
<td>Okay, now that, I'm wondering why over there on the image of the Glass Walls, there appears clicked on the &quot;I&quot; to make another window with text appear on top of the existing VR window. Okay, must be something important...</td>
<td>The user expects real-world conventions to apply to this VE system.</td>
</tr>
<tr>
<td>P10 (1:04:45)</td>
<td>Tenders, what are tenders? Ah, I'm just reading the information about the tenders, cos I have no idea what is tenders.</td>
<td>The user expects real-world conventions to apply to this VE system.</td>
</tr>
<tr>
<td>P11 (1:11:45)</td>
<td>What is Commercial Operation?...</td>
<td>The user expects real-world conventions to apply to this VE system.</td>
</tr>
<tr>
<td>P02 (0:17:43)</td>
<td>Okay, I thought I need to click on &quot;Go&quot;, information comes up (rollover information) and there is this, like a moving the mouse on each image (thumbnail), a very brief...</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
</tr>
<tr>
<td>P02 (0:46:12)</td>
<td>And I was trying here and have to find what is this word, and I don't know why I didn't see it before...</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
</tr>
<tr>
<td>P02 (0:23:21)</td>
<td>Panning around the nodes. Okay, okay, trying to look. How can I find this Royal Box? I mean, I haven't got any clue what this Royal Box (clicked on an embedded hotspot, pop-up)</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
</tr>
<tr>
<td>P02 (0:26:02 - 0:27:36)</td>
<td>I went to the third level (clicked on the three using the map level), I went to the third level (clicked on the embedded hotspot) to see. Yea, this is the level that I'm thinking to find out where is the Opera theater. I went to the Opera theater but what's the difference. This is hard, yeah...</td>
<td>The user is presented with information that does not clearly functionally defined is ignored by the user.</td>
</tr>
<tr>
<td>P02 (0:40:52)</td>
<td>Panning around the node). Oops, okay, trying to look. How can I find this Royal Box (clicked on the QuickTime icon)…</td>
<td>The user expects real-world conventions to apply to this VE system.</td>
</tr>
<tr>
<td>P02 (0:52:23 - 0:58:23)</td>
<td>Umm, I'm wondering what is this thing (rolling over the link for high resolution panoramas), it's an icon for a real player. Click on it to see what it does (click on the QuickTime icon).</td>
<td>The functions of interaction objects provided on the VE were not clearly defined.</td>
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**Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data**

**Textural Information**
- When the user cannot find a clear indication of what the available information is about.
- The information provided on the VE is not clearly defined.
- The user is presented with information that does not clearly functionally defined is ignored by the user.
- The user is presented with information that does not clearly functionally defined is ignored by the user.

**Icons, Symbols and Terms**
- The user expects real-world conventions to apply to this VE system.
- The user expects real-world conventions to apply to this VE system.
- The user expects real-world conventions to apply to this VE system.

**Visual Details**
- The user is presented with information that does not clearly functionally defined is ignored by the user.
- The user is presented with information that does not clearly functionally defined is ignored by the user.
- The user is presented with information that does not clearly functionally defined is ignored by the user.

**User Expectations**
- The user expects real-world conventions to apply to this VE system.
- The user expects real-world conventions to apply to this VE system.
- The user expects real-world conventions to apply to this VE system.
# Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

## Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

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<td><strong>NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P11 (1:16:14) - “Okay, I can see the Shells from the outside now (clicked on an embedded hotspot leading to Opera Theater Foyer South).”</td>
<td></td>
<td>Issue: The user clicked on an embedded hotspot hoping to link to another node or location but the result was not as expected.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sub-broad Themes: location or result.</td>
<td></td>
</tr>
</tbody>
</table>

**NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER - JUMPING**

| P01 (0:07:55) - “Well, it would be nice to actually guide, to give them, like if they are going to tour around, guide them from one site, like let them walk from the west towards (clicked on the yellow ball map link), look around here west and then move around all the way down west. Like how people do walks. Instead of like I have to find here then the next moment I have to be at the other side, the south. It’s confusing.” | | Issue: Jumping is confusing. |
| P11 (0:15:57) - “So it moved further than I thought it would (panning within the VR, rolling over the embedded links, clicked on an embedded hotspot leading to the Opera Theater Foyer East, rolling over the embedded links).” | | Issue: The user traveled a greater distance than the user expected. (perhaps a match between the real world behavior is expected by the user in the VE) |
| P01 (1:27:09) - “... Can I get to see…” | | Issue: The user frustrated with the VE system and therefore gives up what they were trying to accomplish. |

**NAVIGATION - PAN AROUND A LOCATION OR NODE**

| P11 (1:15:57) - “So it moved further than I thought it would (panning within the VR, rolling over the embedded links, clicked on an embedded hotspot leading to the Opera Theater Foyer East, rolling over the embedded links).” | | Issue: The user did not expect to travel a great distance when they clicked on a hotspot. |
| P10 (1:27:06) - “…Can I get to see…” | | The user gets frustrated with the VE system and therefore gives up what they were trying to accomplish. |

**LACK OF FEEDBACK - MAP**

| P10 (1:01:45) - (Reading out loud) | | Issue: The user is frustrated and gives up trying to do a specific task e.g. too busy. |
| P11 (0:16:14) - “(Clicked on Map Level Shells, then Map Level 3, then Shells, then 3) Tak! (mumble, clicked on an embedded hotspot leading to the Box Office Foyer East, rolled over an embedded hotspot and clicked on it leading to Box Office Foyer West) and just heading straight across (Rolled over an embedded hotspot and clicked leading to the Bonnelong Restaurant South, panning within the VR, rolling over the embedded links).” | | The user gets frustrated with the VE system and therefore gives up what they were trying to accomplish. |

## Part 6

SOH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data
Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

Part 7

Issue: The user is exploring the functionality of the map.

The user found that selecting an object on the navigational aid (Map) was a quicker way of navigating between locations.

The navigational aid (Map) provided does not clearly indicate the relocation options to the user.

Issue: User focus is divided between either the map or the VE so the user has to find an alternative way to go to the desired location.

Issue: Map: available locations are not clearly visible to the user e.g. the user has to review the map in order for them to find out what that place is.

Issue: Map: using the map to go to different locations is easier than using the VE.

The user's attention is divided between the VE and the navigational aid (Map).

Issue: Map: using the map to go to different locations is easier than using the VE but the map also has limited functionality that the user had to find another alternative way to go to the desired location.

Issue: The link between the map and the VR is not clearly seen by the user.

The navigational aid (EMBEDDED ARROWS) within the VE system need to have to be clearer links to the 3D map and other objects within the VE system.

Issue: Map: the user found that using 3D balls in a 3D map, for SEARCHING PURPOSES, wastes time as there is no clear indication of where locations are at.

Issue: The user 'tests' functionality of the map e.g. click on specific areas expecting them to lead to another location.

Issue: The user found that selecting an object on the navigational aid (Map) was a quicker way of navigating between locations.

Issue: Map: using the map to go to different locations is easier than using the VE.

The user's attention is divided between the VE and the navigational aid (Map).

Issue: The visual aid (Map) provided does not clearly indicate the relocation options to the user.

Issue: Map: available locations are not clearly visible to the user e.g. the user has to review the map in order for them to find out what that place is.

Issue: Map: using the map to go to different locations is easier than using the VE.

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<thead>
<tr>
<th>SOH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data</th>
<th>Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data</th>
<th>P01</th>
<th>P02</th>
<th>P11</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Issue:</strong> Embedded arrows within the VR are too far away from the map - (divided attention, difficult to link)</td>
<td>P11 (0:32:17) - And I like how on some of the arrows you got information of where you are going to go by looking at the bottom (3D map). It was a bit far away from the arrow (rolling over the 3D balls on the map to show the location label).</td>
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<td><strong>Issue:</strong> Embedded arrows do not clearly indicate where the user can go plus there are a lot of them - (perhaps as the arrows pop up, a text label of where it will go would be useful)</td>
<td>P01 (0:06:58) - And then as I move around this arrow (yellow embedded arrow in the VR) show one part of the dots but it doesn't show me which, where it is now, but some part they do show me, like which direction does it go? (pointing to the Harbor Bridge). It's a bit confusing that times. Go to the sea (clicked on the sea link).</td>
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<td><strong>Issue:</strong> Embedded arrows do not clearly indicate where the user is currently and are only sometimes available in some locations and not others - Objects embedded/used in the VR are not clearly functionally visible</td>
<td>P02 (0:17:43) - I just looked at, at the little small arrow, and I called the name, it matches the symbol, this picture (pointing to the label below the VR). It's a bit confusing that times. Go to the sea (clicked on the sea link).</td>
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<td><strong>Issue:</strong> Objects embedded/used in the VR are not clearly functionally visible</td>
<td>P11 (0:13:27) - Okay, I'm not sure about where the arrows are heading because there are lots of them (clicked on one of the embedded arrows with no location labels leading to Green Room North). &quot;Green Room North&quot; (panning within the VR, rolling over the embedded links). Going to the South again (clicked on an embedded hotspot leading to the Green Room South, clicked on another embedded hotspot leading to Central Passage Stage Door).</td>
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<td><strong>Issue:</strong> Embedded arrows do not clearly indicate where the user can go plus there are a lot of them - (perhaps as the arrows pop up, a text label of where it will go would be useful)</td>
<td>P11 (0:10:07) - Sometimes the arrow tells me where I'm going and sometimes not (0:10:07), which is frustrating (clicked on an embedded hotspot leading to the Concert Hall Foyer South).</td>
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<td>P11 (0:11:36) - (Rolling over an embedded hotspot) and we've got an arrow that doesn't tell me anything (panning within the VR, rolling over the embedded links) so I don't know what that means.</td>
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EXPLORATION IS NEEDED TO FAMILIARIZE ONESELF

Issue: Users stated that they need to find out what is available.

The user explores the functionality of the VE system - options available.

At the conclusion of the text, the user wished that they could have known how to use the system more/better.

The user explores the functionality of the VE system.

Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

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Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

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At the conclusion of the text, the user wished that they could have known how to use the system more/better.

The user explores the functionality of the VE system.
Issue: User wanted to go somewhere by clicking but the system did not respond as expected.

The VE system did not respond as expected to the user's actions.

P10 (0:56:38) - ...the image has (now, panning over the VR to have) the yellow arrows appear as you rolled over an area of the VR (clicked on the embedded hotspot leading to Forecourt Home Position) only one area that I can go back all the way, cos I was very far from the Opera House.

SYSTEM FUNCTIONALITY IS UNDERSTOOD BY THE USER

P10 (0:13:14) - ... So, basically, rolled over the yellow balls on the 3D map to bring up location labels, clicked on one of the yellow balls on the 3D map to go to Box Office Foyer East. I can see these different rooms, on each level, from a different angle of...

P10 (0:50:55) - ... And after that, I have discovered that there is a map over here (rolling over the 3D map) and it's telling me, um, where to go and how can I find the positions and places.

P10 (0:18:11) - Because I didn't realize it was outside because I thought it was from the inside (clicked on an embedded hotspot leading to the Podium Mid-level South). Just heading back to the Opera House (panning within the VR, rolling over the embedded links) and we're going to go down in the bottom, I thought (clicked on an embedded hotspot leading to the Box Office Foyer East, panning around) Not quite the Box Office (that the participant was expecting, panning within the VR, rolling over the embedded links, clicked on an embedded hotspot leading to Car Concourse). And here we go. Cos! (Panning within the VR, rolling over the embedded links, I think I've got itussed.

P10 (0:26:05 - 0:28:20) - Um, I'm thinking to know how, to go from, I, mean, to the start, Where did I start, (clicked on the embedded hotspot), I cannot go back to it from here. Okay, (using the Main Start Page menu, clicked on the Virtual Tour Links).

P10 (0:20:39) - When I went to somewhere, for example here (Broadcourt Home) from the screen (clicked on the embedded hotspot), I cannot return back, I have to look where was the arrow from the (rolling over the 3D map) so I can return back. I don't know if I'm right, maybe because I just start with myself discovering the system...

P10 (0:27:30) - I wonder if I can go back from this place but I don't know how. I have to return to this map (rolling over the 3D map). Is this the right way? Or, is there some? Maybe I want to see the information (clicked on the "i" on the VR, which brought up text about the Concert Hall). Um, What's it actually telling me about the house itself...

P10 (0:28:48 - 0:28:52) - ... I wonder if I can go back from this place but I don't know how. I have to return to this map (rolling over the 3D map). Is this the right way? Or, is there some? Maybe I want to see the information (clicked on the "i" on the VR, which brought up text about the Concert Hall). Um, What's it actually telling me about the house itself...

P10 (0:28:48 - 0:28:52) - ... I wonder if I can go back from this place but I don't know how. I have to return to this map (rolling over the 3D map). Is this the right way? Or, is there some? Maybe I want to see the information (clicked on the "i" on the VR, which brought up text about the Concert Hall). Um, What's it actually telling me about the house itself...

P11 (0:20:20) - - Um, I'm just standing around (panning within the VR) just to see where I can go. Oh, we'll go this way (clicked on the embedded hotspot (yellow arrow) linking to the Box Office Foyer East, rolling over the VR screen, the yellow pointing arrows appear as you roll over the specific spot, the yellow ball on the 3D map bounce, clicked on an embedded hotspot to go to the Podium Mid Level South). Going to the Windmill, No, I went outside. Okay, panning within the VR. Ah, so we come up some stables. (Clicked on an embedded hotspot linking to the Podium South-East.) And then I've gone around the outside? (Panning within the VR using the yellow embedded arrows to locate the yellow ball on the 3D map to determine where the arrow is going to go, clicked on an embedded hotspot linking to the Opera Theater Foyer South, panning within the VR, Cnip, and the yellow ball bounces, clicked on an embedded hotspot (yellow arrow) to the Opera Theater Foyer West, panning within the VR). I'm straight across inside, stables, upstairs. These going toOutside (clicked on an embedded hotspot linking to the Opera Theater Foyer North West, panning within the VR). Just having a look around and see. Just thinking I'm pretty much outside the 3rd level.

P11 (0:01:38 - 0:02:18) - - Uhm, I'm just standing around (panning within the VR) just to see where I can go. Oh, we'll go this way (clicked on the embedded hotspot (yellow arrow) linking to the Box Office Foyer East, rolling over the VR screen, the yellow pointing arrows appear as you roll over the specific spot, the yellow ball on the 3D map bounce, clicked on an embedded hotspot to go to the Podium Mid Level South). Going to the Windmill, No, I went outside. Okay, panning within the VR. Ah, so we come up some stables. (Clicked on an embedded hotspot linking to the Podium South-East.) And then I've gone around the outside? (Panning within the VR using the yellow embedded arrows to locate the yellow ball on the 3D map to determine where the arrow is going to go, clicked on an embedded hotspot linking to the Opera Theater Foyer South, panning within the VR, Cnip, and the yellow ball bounces, clicked on an embedded hotspot (yellow arrow) to the Opera Theater Foyer West, panning within the VR). I'm straight across inside, stables, upstairs. These going toOutside (clicked on an embedded hotspot linking to the Opera Theater Foyer North West, panning within the VR). Just having a look around and see. Just thinking I'm pretty much outside the 3rd level.

Issue: User wanted to go somewhere by clicking but the system did not respond as expected.

The user has limited options available to go back to a previous location - Limited Freedom?

The user demonstrated some basic understanding of how the VE system works.

The system functionality was hidden that the user did not realize other functionalities available.

The system functionality was hidden that the user did not realize other places they can navigate to.
| Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data |
|---|---|---|---|
| Issue: The user is unsure if by clicking on an object that a desired result would be the outcome. |
| SOH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data | Part 11 |
Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

**Issue:** Zooming functionality was hidden to the user

**Sub-broad Themes**

**Part 12**

**Issue**

**POSITIVE COMMENTS ABOUT THE VR PRESENTATION**

Just, just my opinion.

**Part 10** (1:07:09) - If it was embedded hotspot linking to the Opera Theater Foyer North Lounge something, but it's not (panning within the VR, clicked on the "i" to bring up text information about "Gossamer's Exit"), this is not what I'm looking for (clicked close window). Okay, (I'll try that)

**Part 11** (1:20:25) - Dot, the functionality was hidden in the zooming in and out. So I was sort of guessing to find that out.

**IMAGE QUALITY**

**Part 11 (0:02:23)** - I'm having a look at the pictures. It's pretty tiny. I wish that the picture is bigger.

**Part 10 (0:26:04 - 0:33:24)** - It's a question that maybe the picture can be bigger. (It's like people like to see pictures, pictures look worse but big pictures.

**Comments about VR Presentation**

**Part 11 (0:29:49) - Uhm, it was confusing.**

**Part 11 (0:33:50 - 0:35:38)** - Reading the task sheet (imagining seeing this in a bigger view). Can you find out how to make the view of the Concert Hall Auditorium Stage bigger? How can I make it bigger? (Panning within the VR) By just right clicking and zoom (does so using the mouse) I think that's the only way I think. Looks good.

**Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data**

**Issue:** FOV - [observation] the user does not observe that the FOV is not consistent to that in the real world

During the user's first encounter with the VR system, they found it to be too confusing.

**Issue:** The entire purpose of the system is not immediately clear to the user that they think it is something else e.g. a game

During the user's first encounter with the VR system, they found it to be too confusing.

**Issue:** FOV - [observation] the user does not observe the FOV is not consistent to that in the real world navigation

The user's FoV was not consistent to that of the real world when arriving at a destination.

**Issue:** FOV - [observation] there was a lot of information that needed to be read in text together

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Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

P10 - Comments made were mainly about the web

P11 - (0:31:30) - I'm just seeing that at the bottom (the 3D map) and trying to put the two together (the VR and the map). Those, panning over the VR to have the yellow arrows appear as you rolled over an area of the VR. That's quite cool.

Note: The combination of the 3D map and the VE is quite good.

P11 (0:32:17) - And if I click on some of the arrows you get information of where you are going to go to by looking at the bottom (3D map)...

Note: Arrows embedded within the VR correspond to a marker (e.g. ball) on the map.

SUGGESTIONS FOR VE PRESENTATION IMPROVEMENT

P10 (0:28:55) - So, I think this would have been easier. If we had, like this very nice, very nice virtual thing, um, instead of all these buttons, like, all these icons that I have, for example the task is asking me to go to Concert Hall Foyer South. And I have to find out which one of these dots are the exact location. If there was like a combo box thing, which contains all these, the names of all these halls or Foyers, or whatever, that would be easier, just like going through that menu.

P10 (0:53:35) - So you how do you know that you've been to this area before or not?...

P11 (0:31:50) - Pictures are good.

Note: Images (pictures) are really good.

P10 (0:32:01) - "...I like that you can go all the way on the outside as well as the inside."

Note: Using the embedded hotspot allows for easy navigation.

P11 - Comments made were mainly about the web

P11 (0:32:17) - And if I click on some of the arrows you get information of where you are going to go to by looking at the bottom (3D map)...

Note: Arrows embedded within the VR correspond to a marker (e.g. ball) on the map.

Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

Suggestions: An "Node Intro" tool tip - so the user knows when a change between levels has occurred.

Suggestions: More obvious system status changes such as locations already visited, where the arrows are going when a change between levels has occurred.

Suggestions: Embedded arrows need to have little built-in hotspot links)

Suggestions: Embedded arrows need to be more clearly linked with the map and not be covered by the pop-up text that comes up on the map.

Suggestions: A better way of moving between locations (nodes).

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Suggestions: More obvious system status changes such as locations already visited, where the arrows are going when a change between levels has occurred.

Suggestions: Embedded arrows need to be more clearly linked with the map and not be covered by the pop-up text that comes up on the map.

Suggestions: A clear link to the map and system status changes.

Suggestions: An "Node Intro" tool tip" appears as they enter each node.

Suggestions: The user finds it a little confusing when the pop-up hotspot appears on the map.

Suggestions: The user suggests that a "nod/location" tool tip appears as they enter each node.

Suggestions: The user suggests more system status changes such as locations already visited, where the arrows are going when a change between levels has occurred.

Suggestions: The user suggests a better way to navigate between the virtual environment and the outside world. The system status changes need to be provided within the VE system to help the user's spatial orientation.

Suggestions: The user suggests that the system status changes need to be provided within the VE system to help the user's spatial orientation.

Suggestions: The user suggests more system status changes such as locations already visited, where the arrows are going when a change between levels has occurred.

Suggestions: The user suggests that the system status changes need to be provided within the VE system to help the user's spatial orientation.
### Sydney Opera House: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>Experiment - Comments</th>
<th>Issue</th>
<th>Sub-broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>P10 - Comments made were mainly about the web</td>
<td>Issue: Tasks, questions, instructions by the experimenter were ambiguous - not clear</td>
<td>The experimental tasks and instructions were ambiguous to the user</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
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<thead>
<tr>
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<tbody>
<tr>
<td>P11</td>
<td>P10 (0:25:06) - Right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom in, pan within the VR, zoom out again (right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom out). Do you mean on the seats?</td>
<td>(Right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom in, pan within the VR, zoom out again (right clicked on the mouse to bring up the Flash Player 6 pop-up menu, clicked on zoom out). Do you mean on the seats?</td>
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Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

Questacon Science Center: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

### LACK OF FEEDBACK - NO FEEDBACK AS TO HOW THE CURRENT STATE WAS ACHIEVED

<table>
<thead>
<tr>
<th>Pos</th>
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</tr>
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<tbody>
<tr>
<td>P08 (0:26:24)</td>
<td>Um, I’m not quite sure what that did (clicked on the hotspot of white spinning circle with the 4 orange triangles that brings up information about an object) in the first instance but I guess it’s just showing me what this angry arm thing is.</td>
<td>Issue: User does not know what they did to achieve the current system state</td>
</tr>
<tr>
<td>P05 (0:39:42)</td>
<td>...I’m trying to do is just get back to the main introductory script, where I first went into that particular place. How did I do that? That’s in there? (Rolling over the red 3D balls on the 3D map to bring up the location labels), clicked on one of the orange balls on the 3D map to go to another Gallery of Awesome Earth).</td>
<td>Issue: User does not know their current position</td>
</tr>
<tr>
<td>P05 (0:53:07)</td>
<td>...And, that was a good idea. South Roof. I’ve found that. Had no idea which was north, south, west or east; so it’s just a matter of going over a particular indicator to find out which one was the South Roof (clicked on one of the orange balls on the 3D map to go to the South Roof).</td>
<td>Issue: User is not sure of their current position/location</td>
</tr>
<tr>
<td>P08 (0:26:24)</td>
<td>Umm, I wasn’t quite sure what that did (clicked on the hotspot of white spinning circle). Um, I suppose I’m supposed to make the view bigger (Reading the task) but it just went inside. ‘cos I clicked on the spin thing and it flipped inside.</td>
<td>Issue: User does not know what they did to achieve the current system state</td>
</tr>
</tbody>
</table>

### LACK OF FEEDBACK - USER’S SPATIAL LOCATION, ORIENTATION

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<tr>
<th>Pos</th>
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<tr>
<td>P08 (1:02:40 - 1:02:45)</td>
<td>Um, just thinking where I am (Rolling over the 3D orange balls on the 3D map, to bring up the location label). Yelp, (clicked on the Victoria) That I think I’m in the right place. (Clicked on the embedded spiral hotspot link to another part of the Awesome Earth Exhibit).</td>
<td>Issue: User is lost - No indication to the user if they are in the right place (Feedback)</td>
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<tr>
<td>P08 (0:39:42)</td>
<td>...I mean just thinking where I am (Rolling over the 3D orange balls on the 3D map, to bring up the location label). Yelp, (clicked on pan within the VR). That I think I’m in the right place. (Clicked on the embedded spiral hotspot link to another part of the Awesome Earth Exhibit).</td>
<td>Issue: User is lost - No indication to the user if they are in the right place</td>
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<tr>
<td>P08 (0:49:09)</td>
<td>Umm, I can go down rolled over the green spinning spiral. Clicked on the embedded hotspot to the Cafe and have a look at the Questacon cafe. (rolling over the red, 3D balls on the 3D map to bring up the location labels) (clicked on one of the orange balls on the 3D map to the Ramp).</td>
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<td>P08 (0:39:42)</td>
<td>...Um I went inside (into the Fooyer). Yelp, Inside the Foyer Um, Yeah (panning within the VR). I was thinking that I should, did not do it right. Um, ‘cos I supposed to make the view bigger (Reading the task) but it just went inside. ‘cos I clicked on the spin thing and it flipped inside.</td>
<td>Issue: User is lost - No indication to the user if they are in the right place</td>
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### LACK OF FEEDBACK - USER’S SPATIAL LOCATION, ORIENTATION

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### LACK OF FEEDBACK - USER’S SPATIAL LOCATION, ORIENTATION

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### Issue: User gets losts because they easily forget how the locations

- The user does not have a clear mental idea of how the
- The user does not have a clear mental idea of how the
- The user needs to be able to remember the different
- The user needs to be able to remember where they have been and
- The user does not have a correct mental model of how the
- The user does not have a clear mental model of how the
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<td>LACK OF FEEDBACK - SYSTEM STATE</td>
<td></td>
</tr>
<tr>
<td>P08 (0:27:21 - 0:27:45) - Didn't realize what it was actually doing when I was first, when I was first moving around, now I see that it's supposed to take me somewhere else. But I think it's broken (scrolling is taking longer than usual — 5 seconds)... So it's saying it's loading, but it's zero percent of one and it hasn't actually moved.</td>
<td>User: The user does not know the system state especially when something is clicked on and the user is waiting for it to load.</td>
</tr>
<tr>
<td>P08 (0:30:58 - 0:31:43) - I'll have another click on another game (clicked on the hotspot of white spinning circle with the 4 orange triangles that brings up information about an object, nothing happened). Oops, I've clicked properly first time (clicked on the hotspot of white spinning circle with the 4 orange triangles that brings up information about an object), now I have an interactive exhibit (I can see part of...</td>
<td>The user does not know the system state especially when something is clicked on and the user should be waiting for the system to load but does not indicate so. Instead the user tries something else.</td>
</tr>
<tr>
<td>P08 (0:30:35 - 0:30:45) - The user likes the VR, so I've have a way go (doing the activity)... Oops, and they said it's difficult, I think that's what I'm supposed to do (clicking on the screen image), and now what do I do, close the activity.</td>
<td></td>
</tr>
<tr>
<td>P08 (0:30:44 - 0:31:23) - And like, um, also like, uhh, ah, I assume that you can just click on it (on the map) to make it bigger or like right click or something. But it didn't work. And um, yeah, so, and then, and then, I don't know.</td>
<td>The user is finding it difficult to locate another location using either the map or the embedded hotspots.</td>
</tr>
<tr>
<td>P08 (0:24:24 - 0:24:54) - I'm hoping to find some information on maybe how to make it bigger or something. But it's not here. Um, I'm kinda stuck... rolling over the VR, located the spiral hotspot, continued to pan</td>
<td>User: The user is finding it difficult to locate another location using either the map or the embedded hotspots.</td>
</tr>
</tbody>
</table>

| INFORMATION SEARCH - HELP | |
| P08 (0:28:00 - 0:28:21) - Um, the things that I want to know where they are, uh... so I assume that you can just click on it (on the image) to make it bigger or like right click or something. But it didn't work. Um, yeah, so, and then, and then, I don't know. | User: The user does not know how to view a High Resolution VE. |
| P08 (0:11:55 - 0:12:25) - Let me go to the Plant Room here (clicked on the red 3D map that links to the Plant Room). Ooh, I thought that it might have had plants up there. | User: Information such as words, icons, symbols, are not familiar to the user. |
| P08 (0:32:55 - 0:33:46) - Like, "QuickTime VR"... it's like "what does VR stand for?" | Textual information such as words, icons, symbols and terms were not familiar to the user. |

| INFORMATION PRESENTATION | |
| P08 (0:26:54 - 0:27:04) - I've got a look at what that is about (scrolling through the text). Nothing very interesting for me, so I get out of there (panning within the VR) and go and find somewhere else to do. | User: The information presented to the user was found to be "uninteresting" (This leads to the user not reading the presented text thoroughly - see the next few issues as examples). |

QSC: Deriving Sub-broad Themes from the Think-Aloud Protocol Evaluation Data
### Questacon Science Center: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>Issue</th>
<th>Sub-Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-broad Themes: The way the information was presented to the user was unappealing.</td>
<td></td>
</tr>
<tr>
<td><strong>CONTROLLER</strong></td>
<td></td>
</tr>
<tr>
<td>P05 (0:01:38) - Um, I think it’s a hotspot and it just took me to where I clicked on (the cursor over the green spiral hotspot).</td>
<td>User: Controller Buttons presented with the VR does not clearly show its function e.g. controller buttons - (need instructions or feedback of what needs to be done. Otherwise, the functionality to use the system is hidden.)</td>
</tr>
<tr>
<td>P05 (0:33:22 - 0:33:44) - (Clicking on the ‘QuickTime VRs’ link to bring up options ‘Low’ or ‘High’, closed on the ‘High’ option, which brought up a new window with standalone VR of the Patio) (The participant almost closed the window but the QuickTime app appeared, which seemed to stop her from closing the window). Um, I just clicked on the QuickTime VRs link and then clicked on ‘High’. Just to see if it had anything that I want.</td>
<td>The functionality of the VE controller buttons were hidden.</td>
</tr>
<tr>
<td><strong>USER EXPECTATION - OBJECT BEHAVIOR</strong></td>
<td></td>
</tr>
<tr>
<td>P05 (0:29:09) - Clicking on the VR move itself – no effect) I thought maybe by clicking on it, I might be able to zoom in onto something, but it can’t.</td>
<td>User: The user expects real world actions or behaviours to be allowed/ performed within the VE e.g. be able to see outside windows.</td>
</tr>
<tr>
<td><strong>HOTSPOTS LINKS</strong></td>
<td></td>
</tr>
<tr>
<td>P05 (0:29:58) - (Panning within the VR, rolling over the green spinning spiral. Clicked on the embedded hotspot) Not quite sure where these hotspots take me so you’ve just got to click on them to find out (panning within the VR).</td>
<td>User: The user expects real world conventions to apply to this VE system e.g. right click will bring a pop-up menu.</td>
</tr>
<tr>
<td>P05 (0:30:29) - ...And I guess the Science Court is just a place to go and eat, not quite what I expected...</td>
<td>The destination of the hotspot was unclear so the user explores where it will lead them.</td>
</tr>
</tbody>
</table>

### Issue: SEARCHING - The user is looking for hotspots/links to different node/location but since they “can’t find any” [not visible], they click on anything

### Issue: Controller Buttons presented with the VR does not clearly show its function e.g. controller buttons - (need instructions or feedback of what needs to be done. Otherwise, the functionality to use the system is hidden.)

### Issue: The functionality of the VE controller buttons were hidden.

### Issue: The user expects real world conventions to apply to this VE system e.g. right click will bring a pop-up menu.

### Issue: The destination of the hotspot was unclear so the user explores where it will lead them.
| QUESTA CON SCIENCE CENTER: DERIVING SUB-BROAD THEMES FROM THE THINK-ALOUD PROTOCOL EVALUATION DATA | P05 | P08 (0:07:08) - I'm just looking at the options available. | P08 (0:25:09) - My main focus has been on the screen that I'm looking in without actually taking the consideration of any other tabs and places on the screen at the moment. | P05 (0:00:01) - I'm just looking at the options available. | P08 (0:25:09) - Okay, at the moment I'm just having a look to see what's what. | P08 (1:04:00) - I just go disoriented for a moment, and I went over expecting the marble to the Front Entrance, but it's the Patio, so for some reason I've skipped over the Science Court nine, but that wasn't even the Front Entrance. I might click on Outside (clicked on Map Level Outside). | Issue: Hidden hotspots - the user accidentally clicked on the hidden hotspot. This made the user a little bit disoriented as the user didn't know what happened (Feedback needed). | P05 (0:07:08) - I'm just trying to explore and see what else it there in here (panning within the VR). | Issue: Users do not know how to immediately navigate - move from one place to another. | P05 (0:27:47) - Um, I'm just seeing if there is something nice I want to look at, and see where else I can go plus there are a lot of them - [perhaps as the arrows pop up, a text label of where it will go would be useful] | Issue: Embedded arrows do not clearly indicate where the user can go plus there are a lot of them. [Feedback needed]. | P08 (0:40:09) - ...(rolling over the VR and the white object indicators appear) I must have missed them because of the spiral. I think. | Issue: Users stated that they need to find out what is available. | P05 (0:29:23) - And like, it's a bit hard to navigate around. Like on the actual, like when I went up the ramp and stuff. And I was getting a bit lost though, because there wasn't anything telling me where I could go. Like maybe, no signs or anything. And, um, yeah, that was a bit annoying. | Issue: Users do not know how to navigate from one place to another. | P08 (0:29:09) - Reading the task sheet) Okay, somewhere in the Foyer there is a machine called a gravitran, tell me - I didn't even take notice of what the different things were (panning within the VR) | Issue: The user explored the functionality of the VE system - options available. | P08 (1:06:01) - I just go disoriented for a moment, and I went over expecting the marble to the Front Entrance, but it's the Patio, so for some reason I've skipped over the Science Court nine, but that wasn't even the Front Entrance. I might click on Outside (clicked on Map Level Outside). | Issue: Users do not know how to immediately navigate - move from one place to another. | P05 (0:41:17) - Reading the task sheet) Okay, somewhere in the Foyer there is a machine called a gravitran, tell me - I didn't even take notice of what the different things were (panning within the VR) | Issue: The user wished that they could have known how to use the system more/better. | P08 (0:38:47) - I should have explored a little bit more when I had time. But, I think it's because I didn't know there were extra levels. | Issue: The user wished that they could have explored and understood the VE system better. | P05 (0:07:08) - I'm just trying to explore and see what else it there in here (panning within the VR). | Issue: Hidden hotspots - the user accidentally clicked on the hidden hotspot. This made the user a little bit disoriented as the user didn't know what happened (Feedback needed). | P05 (0:29:09) - Reading the task sheet) Okay, somewhere in the Foyer there is a machine called a gravitran, tell me - I didn't even take notice of what the different things were (panning within the VR) | Issue: The user wished that they could have known how to use the system more/better. | P08 (0:38:47) - I should have explored a little bit more when I had time. But, I think it's because I didn't know there were extra levels. | Issue: The user wished that they could have explored and understood the VE system better. | P05 (0:07:08) - I'm just trying to explore and see what else it there in here (panning within the VR). | Issue: Hidden hotspots - the user accidentally clicked on the hidden hotspot. This made the user a little bit disoriented as the user didn't know what happened (Feedback needed). | P05 (0:29:09) - Reading the task sheet) Okay, somewhere in the Foyer there is a machine called a gravitran, tell me - I didn't even take notice of what the different things were (panning within the VR) | Issue: The user wished that they could have known how to use the system more/better. | P08 (0:38:47) - I should have explored a little bit more when I had time. But, I think it's because I didn't know there were extra levels. | Issue: The user wished that they could have explored and understood the VE system better. |
### QUESTACON SCIENCE CENTER: DERIVING SUB-BROAD THEMES FROM THE THINKING-ALoud PROTOCOL EVALUATION DATA

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<tr>
<th>Sub-Broad Themes</th>
<th>Notes</th>
<th>P08 (0:25:09) - Unless there’s some hotspots like this (rolled over the green spinning spiral. Clicked on the embedded hotspot), so it’ll go in here. I’m just having a look to see what happened as a result of clicking there, and it’s obviously taken me inside the building, so I’m just going to have a zoom around to see what’s there (panning within the VR), um, and so I’m going I’m noticing that there’s a few hotspots (rolled over the green spinning spiral), so it’ll go and check those out in a moment.</th>
</tr>
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<tbody>
<tr>
<td>HIDDEN FUNCTIONALITY - STUCK - NO CLEAR &quot;EMERGENCY&quot; EXITS OR &quot;UNDO&quot; OPTIONS</td>
<td>P05 (0:29:17) - ...So, I’ll click on this one again (panning within the VR, rolled over the green spinning spiral). Um, (clicked on the embedded hotspot – green spiral) finding the spinning spiral? Uh, I went inside into the foyer. Yip, inside the foyer Um. Yeah (panning within the VR). I was thinking that I should, did not do it right. Um, coz, I’m supposed to make the view bigger (Reading the task) but it just went inside. &quot;coz I clicked on the spin thing and it navigated inside.</td>
<td></td>
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<tr>
<td>ZOOM IN/OUT - CLOSER LOOK</td>
<td>P08 (0:34:31) – Now I know that I can’t really do anything more once I’ve gone in to have a look to see what the display is about.</td>
<td></td>
</tr>
<tr>
<td>POSITIVE COMMENTS ABOUT THE VR PRESENTATION</td>
<td>P08 (1:07:00) - Um, definitely with the graphics, just having a pop-up window, tell me uh, what the name of the place I would be going to, that would be really big help for me.</td>
<td></td>
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### Questacon Science Center: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

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<td>(0:38:05 - 0:38:35)</td>
<td>(Clicked on the embedded hotspot to the Foyer) (0:38:55)</td>
<td>...is that what meant by the spinning spiral, that thing?</td>
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<td>(0:36:55 - 0:37:24)</td>
<td>Um, (0:37:00) Actually just, (rolling over the 3d orange balls on the 3D map to bring up location labels), um, you had &quot;Front Entrance&quot; or something over here. I just assumed that the Front Entrance was the Patio coz I think it says, it's different, coz I think because this is called the Foyer, and this is the Patio. So I wasn't sure if the Patio is the Front Entrance.</td>
<td>The experimental tasks and instructions were ambiguous to the user</td>
</tr>
<tr>
<td>(1:09:34 - 1:09:34)</td>
<td>Umm, the tasks were fine, I did get a little bit confused just with the instructions... Like when it was return to the Foyer... I wasn't sure if I was allowed to go outside of the Foyer picture, and to use the other menu options to actually complete the task... Um, so there was that one, and there was another one I just wasn't quite sure about, either... But there was nothing too major that upset me. But the tasks were fairly self explanatory, and fairly simple and it did test my knowledge of how I needed to get about... And how I need to find things.</td>
<td>Good: Cameras were not in the face</td>
</tr>
<tr>
<td>(1:09:04 - 1:09:34)</td>
<td>Okay. (Laugh). I like the way set up where the cameras, I knew weren't going to be on my face... I liked that and um, knowing that the cameras were on the screen and on my hands, and that was about all that was going to be seen of me, was good. Yeah, yeah, and also just, coz you know, I must, I probably would have had some puzzled looks on my face. (Laugh) I'd look stupid though, so I was glad that I didn't have to worry about that. But I did wonder, a little bit as I was speaking, if what I was saying was just rubbish...</td>
<td>Recording of the data using the video camera was unobtrusive</td>
</tr>
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<td>(1:08:34 - 1:08:34)</td>
<td>Okay. (Laugh). I like the way set up where the cameras, I knew weren't going to be on my face...</td>
<td>Good: Cameras were not in the face</td>
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<td>(0:38:05 - 0:38:35)</td>
<td>...is that what meant by the spinning spiral, that thing?</td>
<td>Issue: Tasks, questions, instructions by the experimenter were ambiguous - not clear</td>
</tr>
</tbody>
</table>

QSC: Deriving Sub-broad Themes from the Think-Aloud Protocol Evaluation Data

Part 20
Cause of Feedback: User's Spatial Location/Orientation

Issue: User is lost. No indication to the user if they are in the right place (Feedback).

The user does not know their current position.

Part 21
Issues

Issue: The user expects the presented object such as when the doorway to bring to the Chapel. Okay. (clicked the Back button on the Internet Explorer to go back a page, clicked on another to go direct there. But I have to go (moving the cursor around the area of the Entrance Hall, chairs in the Wroxton Chapel.) I actually see the entrance to the Chapel and so I would like…)

Issue: Controller - the button functions were not immediately clear. For example, "Show Hotspots" in the QuickTime Viewer controller.

Issue: There is a lot of information presented to the user. Therefore, the information presented to the user was often skimmed over rather than read in detail.

Issue: The user expects the presented object such as when the doorway to bring to the Chapel. Okay.

Issue: The user commented that without the option to "show the hotspots", the user would not know where they are located and able to click.

Issue: There is a lot of information presented to the user. Therefore, the information presented to the user was often skimmed over rather than read in detail.

Issue: The user expects real world actions or behaviours to be allowed/performed within the VE e.g. able to see outside windows.

Issue: The functionality of the VE controller buttons were hidden.

Issue: The user expects real world conventions to apply to this VE system

Issue: The user expects the presented object such as when the cursor changes inside the VR to work but there is no feedback as to why it’s not working

Issue: The user expects to be able to feel like they are walking towards a location e.g. down the Hall - the need for transitions to simulate real-world walking.

Issue: The user expects to be able to feel like they are walking towards a location e.g. down the Hall - the need for transitions to simulate real-world walking.

Issue: The user expects world conventions to apply to a VE system e.g. right click will bring up a pop-up menu

Issue: The user expects the presented object such as when the cursor changes inside the VR to work but there is no feedback as to why it’s not working

Issue: The user expects to be able to feel like they are walking towards a location e.g. down the Hall - the need for transitions to simulate real-world walking.

Issues

Issue: Controller Buttons presented with the VR does not clearly visible so the user clicks on anything within the VE.

Issue: The way the information was presented to the user was unappealing.

Issue: The user expectations are not met when clicking on a hotspot on the controller.

Issue: The user may think that they have missed a hotspot because they did not see the results of their action.

Issue: The user commented that without the option to "show the hotspots", the user would not know where they are located and able to click.

Issue: The user expects real world actions or behaviours to be allowed/performed within the VE e.g. able to see outside windows.

Issue: The functionality of the VE controller buttons were hidden.

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Wroxton Abbey (WA): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

P03

Sub-broad Themes

Issue: The image/map presents two story building but the VR only

Issue: Panning within the VR is hard to control because it moves

Issues

The navigational aid (Map) provided is incomplete

The user clicked on an embedded hotspot hoping to link to another
node or location but the result was not as expected.

The location of the hotspot was in an unexpected area

The user does not know how to navigate from one place to

another.

The user did not know how to pan around with the VR

The user did not know how to pan/rotate within the VE

The user did not know how to pan/rotate within the VE

The user found the panning speed of the VE too fast.

The user stated that the navigational aid (Map) does not match
to that of the presented VE.

The user found that selecting an object on the navigational aid
(Map) was a quicker way of navigating between locations.

The navigational aid (Map) provided is incomplete

NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER

NAVIGATION - ROTATION - PAN AROUND A LOCATION OR NODE

NAVIGATIONAL AID - MAP

NAVIGATION / ROTATION - PAN AROUND A LOCATION OR NODE

NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER

NAVIGATIONAL AID - MAP
Wroxton Abbey (WA): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

### Issues

**Limitation of Freedom**

- User has limited movement/access to places within the VE.

**User Interface**

- Location of the map relative to the VE window is frustrating to the user as it causes the user to scroll down.

**System Functionality**

- System functionality is understood by the user.

**User Exploration**

- The user demonstrates some basic understanding of how the VE system works.

### Sub-broad Themes

**Limited Freedom - Constraint Access**

- The user has limited movement/access to places within the VE.

**User Exploration**

- The user explores the functionality of the VE system - options available.

**System Functionality is Understood by the User**

- The user understands the basic functionality of the system e.g. if you click this, this will result (be in line with EXPLORATION OF ACTION WITH RESULT).
**Wroxton Abbey (WA): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data**

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<tbody>
<tr>
<td>P03</td>
<td>P09</td>
<td>P12</td>
<td>Issues</td>
<td>Sub-broad Themes</td>
<td></td>
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<tr>
<td>P03 (0:36:43 - 0:37:09) - And, uh, And I think, it’s hard to pan up and down here outside. And when like your inside, you can most of the time, look around 360 degrees but here it’s limited to like 45 degrees.</td>
<td>P09 (0:00:57) - ...It seems that it’s possible to go back to the back of the house too (from looking at the map, clicked on embedded hotspot) “Preview of Lakes and Grounds.” Okay now, I’m on the other side of the house and I’m not in the VR environment anymore, these are just pictures of the ground and lakes.</td>
<td>P12 (0:09:49) - Um, and that’s stuck, don’t know what to do. Just try zooming in and out (Zoom in using the plus button on the controller, zoom out using the minus button on the controller).</td>
<td><strong>Issue:</strong> The user was stuck in a particular location and had to use alternative ways to get out e.g. map.</td>
<td><strong>Sub-broad Themes:</strong> The user was stuck in a particular location and used an alternative way to exit.</td>
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<tr>
<td>P03 (0:18:40) - Not sure how to get back to where I originally started from, from the entrance.</td>
<td>P09 (0:18:47) - Just trying to click into the right, to move to the right or left, but it doesn’t work.</td>
<td></td>
<td><strong>Issue:</strong> The user was unsure how to go back to where they came from.</td>
<td><strong>Sub-broad Themes:</strong> The user was unsure how to undo an action.</td>
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**Sub-broad Themes:**

- **Hidden Functionality:** Stuck, no clear “Emergency” exits or undo options
- **Stuck:** Users were stuck in a particular location and had to use alternative ways to exit.
- **No Clear "Emergency" Exits or Undo Options:** Users were unsure how to undo an action.
Wroxton Abbey (WA): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

### ROOM SIZE - CLOSER LOOK

**P3 (01:30):** I think it’s nice but probably better if you can go closer, like the interesting part, the interesting part, handcraft here (zoom), like that pillar here, it gets more blurred here.

**P3 (01:16):**...I’d be able to see a bit more, I’m looking up, I don’t know how to re-size it (01:19:44). Oh, okay, here we go, let’s go up to the top, let’s talk, the image quality is good.

**P12 (4:22:55 - 4:47:37):**...I would like to be able to have a closer look at some of the painting and stuff.

Issue: The user would like to take a closer look at the different objects within the VE but cannot - model with the real world?

Sub-broad Themes

The functionality to zoom in and out to look in closer detail was hidden from the user.

The user would like the VE system images to be bigger.

### IMAGE QUALITY

**P3 (05:18):**...As you can see, you can zoom in a bit but after while it becomes a little bit blurred. I think. So zoom more makes the picture a little bit more blurred and not very interesting to look at...

**P3 (05:18):**...I’m interested in the ornaments around it so I decide to zoom. But still you get a little bit blurred...

**P3 (05:25):**...I think it’s nice but probably better if you can go closer, like the interesting part like the interesting part, handcraft here (zoom), like that pillar here, it gets more blurred here. It would be nice to have more sharpened. Like this, this soldier outfit here will be interesting to look around. Maybe it’s a trade-off between having an exploring like the flying bird/person in a building rather than having a reality with a person having a walk around, it still looks really blurred and needs sharper picture but then again, you can save or print it.

**P3 (05:12):**...To me it looks like “E.” few new light bulbs which consists of base layers of sand, hallway, and so before and those on the next one. It’s a little bit hard to see from this angle...

**P3 (05:14):**...I don’t think it’s easy but at some time this detail (very tiny) make you want to discover the details more...

**P12 (4:37:52 - 4:50:00):**...It’s quite um, quite realistic. And the use of the photo images (panning within the VR), is the other way around – should face towards the Great Hall but again facing the entrance to the Library (0:18:12).

**P12 (4:17:41):**...Just going back to when I came from here (zoom) on the black grey area on the lower to return to the Great Hall. FOV is the other way around – should face towards the exit door but again, facing the entrance to the Library (0:18:12).

**P12 (4:20:23):**...[Clicked on the Back Gray arrow on the screen to return to the Entrance Hallway - FOV is the other way around - should face towards the Great Hall but again facing the doorway to the South Wing Premier].

**P12 (4:18:47 - 4:19:37):**...Just going to zoom out (zoom out using the minus button on the controller) and look on the hotspots button again (clicked on the “Show Hotspots” icon on the controller), cos once I got in these positions, I’m looking up now, I don’t know how to reset it (0:19:44). Oh, okay, here we go, let’s go up to the top, let’s talk, the image quality is good.

**P12 (4:08:42):**...Because it’s quite small and you can’t look and get close up looks at all the things that you may want to see. Uhm, they could have had more of the VR things instead of pictures or something. Like the outside lady, you might want to get nice views of the outside. It was like, round the back (scrolling down the page to look at the map) and stuff...

**P12 (4:05:20 - 4:05:30):**...Is that a flag rolled up or something? I’m not sure that’s what it is. It’s a blue flag...

**P12 (4:06:18 - 4:06:33):**...I think it is something that is for viewing the map, if you could click on these things (letters and numbers on the map) - leads to a page with images of the surrounding garden and park...

**P12 (4:53:30):**...Anyway, back to the Great Hall (clicked on the black arrow on the website and now I’m facing, I’m still facing the entrance to the library instead of having my back towards the library so I feel like I’ve been teleported instead of walking around in this environment and I get back into the Entrance Hallway...

**P12 (4:55:30):**...Walking towards the village (on the map) and I can’t, I don’t see that one before. You can actually to the village. (Clicked on the map). Uhm, I wanted to visit the village but instead I’m facing the Wroxton Abbey...

**P12 (4:53:30):**...Maybe it would be easier if I enter the room, instead of standing in the middle of the room come and in at the new view site – should face towards the exit door but again, facing the entrance to the Library (0:18:12).

**P12 (4:07:50):**...And, okay, [clicked on the embedded hotspot], now inside the fancy hall here and now the instructions for the tour come in, just when I want to explore it...

**P12 (4:03:42 - 4:03:50):**...And, Uhm. And then, I didn’t know why I had to pan up and down here outside. And when you inside, you can move the time, look around 360 degrees but here [outside] it’s 45 degrees...

**P12 (4:07:50):**...Now here’s a button that shows all the hotspots. It’s a very nice way to navigate. Is it improved? If the virtual reality, it makes it very easy to navigate. I like the transparency of it...

**P12 (4:04:30):**...Now here’s a button that shows all the hotspots. It’s a very nice way to navigate. Is it improved? If the virtual reality, it makes it very easy to navigate. I like the transparency of it...

**P12 (4:03:11):**...Now here’s a button that shows all the hotspots. It’s a very nice way to navigate. Is it improved? If the virtual reality, it makes it very easy to navigate. I like the transparency of it...

**P12 (4:00:01):**...Now here’s a button that shows all the hotspots. It’s a very nice way to navigate. Is it improved? If the virtual reality, it makes it very easy to navigate. I like the transparency of it...

**P12 (3:20:00):**...Now here’s a button that shows all the hotspots. It’s a very nice way to navigate. Is it improved? If the virtual reality, it makes it very easy to navigate. I like the transparency of it...
The user commented that they liked they can pan around a house. And I really think the way the hotspots have this (on) once you press around in that area, you probably would have discovered without this hotspot tool. And I really think that way the hotspots manual is. So once you press around in that area, you probably would have discovered it. I really think it would help. I think this was a great game.

Sub-broad Themes

The user commented that the form of navigation, like when I was thinking (panning up and down, and I didn’t even really think to push that button. Once I did it, I saw like it seemed a really simple thing to do but I didn’t really think in the instructions that you had to hold the mouse button down. I was just expecting to move it from left to right and up and down. So I had a bit of trouble finding that. And just a bit of confusion about what a proxy was really.

Suggestion: Information on what the VR should do so that users know they can pan around (move left to right, vice versa). The system functionality should be more visible especially on how to navigate.

Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

The navigational aid (EMBEDDED ARROWS) within the VE is still feels like I’m using a binocular. So you can use the toolbars. The way you can look around (paving upwards and rotating within the VR), I know, like when I think, what’s the scene? you sort of think I’ve got to look up.

Suggestion: The user is suggesting that a better way to navigate between the nodes/locations would be better such as a drop-down list or a combo box. The user commented that without the option to “show the hotspots”, the user would not know where they are located and able to click. The user commented that they liked that they can pan around a location.

P09 (0:39:49 - 0:39:54) - Well, one thing I didn’t like was, that, well from my point of view, really, was those instructions. I have getting a bit frustrated with thinking, you know, surely this must work. And I had to go back about two or three times to figure out, and even by reading the instructions. I didn’t really figure out. I sort of meant to go up and down, and it didn’t tell me how to do it. That was frustrating.

P09 (0:43:45 - 0:44:01) - I think if I needed to say it’s on the left side, to the right, this was that you had to hold down this mouse. Oh, I needed it. I just read that as dragging. Yes, see, so, here’s where my confusion was. Does actually say drag the cursor, but I’ve just interpreted that as dragging, just dragging. Yeah I did so, I’m so sorry. Just go into that pretty yellow picture there was the (pop up toolbar). It hides that thing (the text) that says drag... (Laugh). Yeah that’s probably, so I’ve sort of made up, um, just recorded that. Say “to pan the image hold the left mouse button down.”

Suggestion: More obvious system status changes such as locations already visited, where the arrows are going, when a change between levels has occurred.

P09 (0:40:10) - And I think it’s should be able to have more hotspots, to like, I didn’t know what the purpose of the tour was.

Suggestion: The user suggested that they should have the flexibility to use both the keyboard and the mouse to navigate within the VE.民用户 said that when they get mixed up, you use mouse, so you can see it.

P09 (0:40:41 - 0:41:05) - So maybe it’s should be able to have more hotspots. I’m a bit a little bit limited in what I need, when you get mixed up, it’s probably better to actually use the keyboard and the same time you use mouse, so you can see it.

Suggestion: Have the flexibility to use both the mouse and the keyboard to navigate. The user suggested that there should be more hotspots available e.g. outside Richard Straw’s part of 27.
The user suggested that there should be a clearer link between the navigational aid (EMBOLDENED ARROWS) within the VE. The tooltip that pops-up should not cover the VE.

The user suggested that the navigational aid (Map) provided should be at the same level as the VE window.

The user suggested that perhaps an audio guide would better enhance the VE experience.

The user suggested that perhaps different perspectives of the same location can be made available in the VE.

The user suggested that there should be a quicker way of navigating such as a drop down list or combobox.

The user suggested that perhaps an audio guide would better enhance the VE experience.

The user suggested that a more powerful zoom would allow the user to look farther into the area.

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### Richard Strauss House (RSH): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

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<thead>
<tr>
<th>Issue</th>
<th>Sub-broad Themes</th>
</tr>
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<tbody>
<tr>
<td>Lack of Feedback</td>
<td>Users Spatial Location, Orientation</td>
</tr>
<tr>
<td>P07 (1:02:31 - 1:03:01)</td>
<td>... Umm, where do I want to go (Rolling over the 3D map to bring up the location label). Umm, that's queer, I haven't been to the Salon or the Library so we'll try the Salon first (Clicked on one of the rooms on the 3D map leading to the Salon). Which is not that way, just through this one…</td>
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<td>Issue: The user is finding it difficult to locate the answer to an assigned task question</td>
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<tr>
<td>P08 (1:06:44)</td>
<td>... I think I've covered all the rooms, haven't read anything about each room, but looks kind of boring, just reading a little like file, one of the rooms in the Study, it's quaking school of got bored with that, moving on something else…</td>
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<td>P09 (1:03:30)</td>
<td>... I would want to know a little bit about the grounds around how the old caretaker's buried down over the fence or something. You know, that sort of stuff. I was expecting a little bit more…</td>
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<td>P18 (1:06:44)</td>
<td>... I think I've covered all the rooms, haven't read anything about each room, but looks kind of boring, just reading a little like file, one of the rooms in the Study, it's quaking school of got bored with that, moving on something else…</td>
</tr>
<tr>
<td>Issue: The information presented to the user was found to be &quot;boring&quot;</td>
<td></td>
</tr>
<tr>
<td>P19 (1:03:30)</td>
<td>... I would want to know a little bit about the grounds around how the old caretaker's buried down over the fence or something. You know, that sort of stuff. I was expecting a little bit more…</td>
</tr>
<tr>
<td>Issue: The user is finding it difficult to locate the answer to an assigned task question</td>
<td></td>
</tr>
<tr>
<td>P20 (1:06:44)</td>
<td>... I think I've covered all the rooms, haven't read anything about each room, but looks kind of boring, just reading a little like file, one of the rooms in the Study, it's quaking school of got bored with that, moving on something else…</td>
</tr>
<tr>
<td>Issue: The information presented to the user was found to be &quot;boring&quot;</td>
<td></td>
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<tr>
<td>P21 (1:03:30)</td>
<td>... I would want to know a little bit about the grounds around how the old caretaker's buried down over the fence or something. You know, that sort of stuff. I was expecting a little bit more…</td>
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<td>Issue: The user is finding it difficult to locate the answer to an assigned task question</td>
<td></td>
</tr>
<tr>
<td>P22 (1:06:44)</td>
<td>... I think I've covered all the rooms, haven't read anything about each room, but looks kind of boring, just reading a little like file, one of the rooms in the Study, it's quaking school of got bored with that, moving on something else…</td>
</tr>
<tr>
<td>Issue: The information presented to the user was found to be &quot;boring&quot;</td>
<td></td>
</tr>
<tr>
<td>P23 (1:03:30)</td>
<td>... I would want to know a little bit about the grounds around how the old caretaker's buried down over the fence or something. You know, that sort of stuff. I was expecting a little bit more…</td>
</tr>
<tr>
<td>Issue: The user is finding it difficult to locate the answer to an assigned task question</td>
<td></td>
</tr>
<tr>
<td>P24 (1:06:44)</td>
<td>... I think I've covered all the rooms, haven't read anything about each room, but looks kind of boring, just reading a little like file, one of the rooms in the Study, it's quaking school of got bored with that, moving on something else…</td>
</tr>
<tr>
<td>Issue: The information presented to the user was found to be &quot;boring&quot;</td>
<td></td>
</tr>
<tr>
<td>P25 (1:03:30)</td>
<td>... I would want to know a little bit about the grounds around how the old caretaker's buried down over the fence or something. You know, that sort of stuff. I was expecting a little bit more…</td>
</tr>
<tr>
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Richard Strauss House (RSH): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>Theme</th>
<th>Issue</th>
<th>Quote</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>USER EXPECTATION - OBJECT BEHAVIOR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P04 (1:02:15) - Um, no, it wasn’t generally that good, sometimes a little bit intuitive I supposed, maybe. Just thing is, that I thought maybe there should be more, because you want things to be more intuitive. But there wasn’t anything…</td>
<td>The user expects real world conventions to apply to this VE system</td>
<td>The functionality of the VE controller buttons were hidden.</td>
<td></td>
</tr>
<tr>
<td>P06 (0:39:15) - Right key, right mouse key (does not do anything). Just try the plus button on the controller, but I can’t see out of the window (Panning within the VR)</td>
<td>The functionality of the VE controller buttons were hidden.</td>
<td>The functionality of the VE controller buttons were hidden.</td>
<td></td>
</tr>
<tr>
<td>P04 (1:01:41) - …there is a door you can’t go into (tried clicking that particular area within the VR, passing within the VR)</td>
<td>The user expects objects to be interactive e.g. able to open doors of cabinets etc</td>
<td>The user expects objects to be interactive e.g. able to open doors of cabinets etc</td>
<td></td>
</tr>
<tr>
<td>P07 (1:02:31) - I couldn’t find the door from the Study to the Hallway, and on the map it looks like there is a door on the floor from there to there.</td>
<td>The user expects objects to be interactive e.g. able to open doors of cabinets etc</td>
<td>The user expects objects to be interactive e.g. able to open doors of cabinets etc</td>
<td></td>
</tr>
<tr>
<td>P04 (1:02:38 - 1:04:20) - …if I clicked and drag it that way, I would have expected the room to move in the other way, maybe. It’s doing it the opposite. So if I click and drag the mouse on the right, I would have expected it to move in the other direction. I’m pulling it over that way, towards the right. Pulling the mouse, towards that direction (towards the right); clockwise, I’m pulling for the right, I mean, I’m confused now. Um, okay, if it’s to the right, I expect the mouse to rotate to the right. But if it’s going round to the right, if I pull it to the right, I expect to see the left side of the desk, but it goes the other way. Narrow sense? So, okay, I’m going to move this across to the right. So, it’s doing it the other way.</td>
<td>The user expects real world conventions to apply to this VE system</td>
<td>The user expects real world conventions to apply to this VE system</td>
<td></td>
</tr>
<tr>
<td>P05 (1:13:38 - 1:15:17) - Um, I want to zoom into that picture but I can’t. Because I can only zoom in straight ahead but if I move around a bit, see how I want the seeing way? Because it wasn’t the way I expected. And if I zoom, I want to zoom into that picture, but I can’t. I mean, I can’t. I just can’t go up and down or I don’t know how to go up and down. And, the arrows tend to indicate that. So, they’re not working too well for me.</td>
<td>The user expects real world conventions to apply to this VE system</td>
<td>The user expects real world conventions to apply to this VE system</td>
<td></td>
</tr>
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</table>

Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data
### Richar Strauss House (RSH): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>PhR</th>
<th>PhR (1:30:36) - &quot;You kind of slip past them and you don’t realize, see everything looks the same&quot;</th>
<th>PhR (1:01:06) - &quot;You kind of zip past them and you don’t realize, cos everything looks the same&quot;</th>
<th><strong>Issue:</strong> The user expects to be able to feel like they are walking towards a location e.g. down the Hall - the need for transitions to simulate real world walking.</th>
<th><strong>Sub-broad Theme:</strong> Transition to simulate real world walking.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Issues</strong></td>
<td><strong>Sub-broad Theme</strong></td>
<td><strong>Issue:</strong> The user expects to be able to feel like they are walking towards a location e.g. down the Hall - the need for transitions to simulate real world walking.</td>
<td><strong>Sub-broad Theme:</strong> Transition to simulate real world walking.</td>
<td></td>
</tr>
<tr>
<td><strong>HOTSPOTS/LINKS</strong></td>
<td><strong>Issue:</strong> The links to the hotspots were not clearly visible so the user clicks on anything within the VE.</td>
<td><strong>Issue:</strong> The user accidentally clicked on a hotspot that brought them to an unexpected location. Thus making them disoriented.</td>
<td><strong>Issue:</strong> Hidden hotspots - the user accidentally clicked on the hidden hotspot. The user did not know what happened (feedback needed). This leads to the user trying something else.</td>
<td></td>
</tr>
<tr>
<td>PhR (1:07:29) - &quot;I had no idea what I did there (accidentally clicked on an embedded hotspot to the Dining Room)&quot;</td>
<td><strong>Issue:</strong> Hidden hotspots - the user accidentally clicked on the hidden hotspot. This made the user a little bit &quot;disoriented&quot; as the user did not know what happened (feedback needed). This leads to the user trying something else.</td>
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<td><strong>Issue:</strong> Hidden hotspots - the user accidentally clicked on a hotspot which they did not mean to do.</td>
<td></td>
</tr>
<tr>
<td>PhR (1:07:22 - 1:07:36) - &quot;Maybe if I go back along the... than started double clicking within the [map]? I think. Yeah. I double clicked but I don’t know what took me there. Maybe I’m clicking near a hotspot. See if I can find that soon again.&quot;</td>
<td><strong>Issue:</strong> Location of the hotspot. The user did not expect the hotspot to be located at their current place, i.e. down the Hall, so the user would expect to see things passing by as, and objects coming closer and that kind of thing.</td>
<td><strong>Issue:</strong> Location of the hotspot. The user did not expect the hotspot to be located close to that particular area. This could be due to the user not knowing where the hotspot was.</td>
<td></td>
<td></td>
</tr>
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</table>
| PhR (1:23:40) - "the hotspot, it didn’t show how you could click to show where they are. So if you don’t know that it’s hard to know which parts of the object are hotspots. So if you’re looking at the hotspot to see if something’s there then you’ll do anything, it’s too men a completely different room. Whereas, I would expect that if it clicked on the door area."

### Part 31

**RSHE Deriving Sub-broad Themes from the Think-Aloud Protocol Evaluation Data**

**Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data**
### Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

#### Richard Strauss House (RSH): Deriving Sub-broad Themes from the Think-Aloud Protocol Evaluation Data

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<td>Users did not know how to pan/turn/rotate within the VE.</td>
<td>The user did not know how to pan around with the VR</td>
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<tr>
<td>Users did not know how to pan/turn/rotate within the VE.</td>
<td>The user needs to be able to remember where they have been and they do this by remembering numbers on the map rather than what it actually is e.g. No. 5 in the study</td>
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<tr>
<td>Users did not know how to pan/turn/rotate within the VE.</td>
<td>The user is trying to remember where they have been (explored). They wonder why some areas on the map are not accessible (does not have a hotspot). There is no feedback (explanation) as to why this is so.</td>
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#### NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER

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#### NAVIGATION / ROTATION - PAN AROUND A LOCATION OR NODE

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#### LACK OF FEEDBACK - MAP

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#### NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER

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<td><strong>Issue</strong></td>
<td><strong>RSH: Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data</strong></td>
</tr>
<tr>
<td><strong>P04</strong> (1:20:33 - 1:21:41) - Just two. See I can't go up and down over here. You don't have any means. I could walk up, but I can't just walk up here. Uhm, 'From here, using the virtual reality itself find your way back to the start'. So, I'll explore it first. I can still go round a circle and still can't go up and down. Hard luck. And that's about enough exploring.</td>
<td>Issue: User is frustrated and gives up trying to do a specific task e.g. too lazy</td>
</tr>
<tr>
<td><strong>P06</strong> (0:41:16) - Can't go up the stairs, want to go up the stairs, but can't go up the stairs (tried clicking that particular area within the VR).</td>
<td>Issue: The user is frustrated with the VE system and therefore gives up what they were trying to accomplish.</td>
</tr>
<tr>
<td><strong>P07</strong> (0:03:27) - So I'll see what else, up on the top map, is where we want to go.</td>
<td><strong>The user stated that the navigational aid (Map) does not match to that of the presented VE.</strong></td>
</tr>
<tr>
<td><strong>P04</strong> (1:25:35) - The map is, is like the map, I found that it's much easier to just use the map than it was to use the actual the virtual reality thing in the finding the hotspots because you can just hold the mouse over the map and see which rooms, uh, each number relates to and click on it.</td>
<td><strong>The user's attention is divided between the VE and the navigational aid (Map).</strong></td>
</tr>
<tr>
<td><strong>P06</strong> (1:00:50) - I didn't really like the way it said it up there (mouse rollovers on the 3D map of the different rooms) when you went over them, it was kind of, when I wanted to have a quick look at the map, to see where I wanted to go, I was kind of, I, I used to move the mouse over the top of the thing to look out and if it gets busy, instead of just using the mouse rollover to see if it's a new room, or possibly knowing where to go and in the house. To get to a certain place.</td>
<td><strong>The user stated the navigational aid (Map) does not match to that of the presented VE.</strong></td>
</tr>
<tr>
<td><strong>P06</strong> (0:38:00) - Looking at the two story building but the VR only shows the bottom level. The user expected to be able to see all locations.</td>
<td></td>
</tr>
<tr>
<td><strong>P04</strong> (1:18:28 - 1:19:07) - &quot;From the kitchen&quot; (moving the cursor over the map), so going in... can't find the kitchen on this window (only one window anyway) on this thing, from this thing (map). Hall, Dining Room, Bay Window. (Clicked on the Lounge) Hall (clicked on Hall), (clicked on Hotspot within the Hall) that takes me to the Dining Room. I want the Kitchen. That's obvious, or possibly knowing where to go and in the house. To get to a certain place.</td>
<td><strong>The link between the map and the VR is not clearly seen by the user.</strong></td>
</tr>
<tr>
<td><strong>P07</strong> (0:22:16) - So you obviously only had a rough idea of the ground floor. And as long as it is laid out the way the map says here, then yeah, I think you'd have a pretty good idea of how to get around, and where things were. definitely. Once you actually get in, you've a bit hard to see an actual desk from here. But I'm sure that's obvious once you're at the house.</td>
<td><strong>The user's attention is divided between the VE and the navigational aid (Map).</strong></td>
</tr>
</tbody>
</table>
### Richard Strauss House (RSH): Deriving Sub-broad Themes from the Think-Aloud Protocol Evaluation Data

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<tbody>
<tr>
<td>The user has limited access to places.</td>
<td><strong>LIMITED FREEDOM - CONSTRAINT ACCESS</strong></td>
<td></td>
</tr>
<tr>
<td>Issue: The user has limited access to places.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Issue: Without the map it's hard to remember how to get out or move around.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Issue: Users stated that they needed to find out what is available</td>
<td></td>
<td>The user explores the functionality of the VE system - options available.</td>
</tr>
<tr>
<td>Issue: User wanted to go somewhere but it's unsure if it is possible or not.</td>
<td></td>
<td>The user wishes that they could have known how to use the VE system better.</td>
</tr>
<tr>
<td>Issue: User wanted to go somewhere by clicking but system did not respond as expected.</td>
<td></td>
<td>The user has limited access to places.</td>
</tr>
</tbody>
</table>

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### Table of Quotes: Richard Strauss House (RSH)

<table>
<thead>
<tr>
<th>Quote</th>
<th>Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I think I will have a good picture of each room individually, but not the house as a whole. And not the ceilings and the floors because I couldn't see them, the ceilings and the floors.”</td>
<td>1:27:27 - 1:28:35</td>
<td></td>
</tr>
<tr>
<td>“The user's attention is divided between the VE and the navigational aid (Map).”</td>
<td>1:00:54 - 1:01:04</td>
<td></td>
</tr>
<tr>
<td>“The user explored the functionality of the VE system - options available.”</td>
<td>1:03:12 - 1:03:18</td>
<td></td>
</tr>
<tr>
<td>“At the conclusion of the test, the user stated that they could have explored and understood the VE system better.”</td>
<td>1:18:09 - 1:18:19</td>
<td></td>
</tr>
<tr>
<td>“I think that we can’t go to. Hang on! Apparently I can go there but they’re not numbered. Going up (exploring the map) I click on that little green bit (up 2) it will take me to the hall, which is just part of the house. But it’s a different colored green that is not attached to sections in the room.”</td>
<td>0:58:59 - 0:59:05</td>
<td></td>
</tr>
<tr>
<td>“I wonder if you can go up and down (dragging the cursor up and down), but you can’t go in and out, just the left and right (panning within the VR). Going around (panning within the VR) just showing the hotspots (clicked on the ‘Show hotspots’ box on the controller), just in case there is anything up there; I can’t see, no.”</td>
<td>0:50:47 - 0:50:52</td>
<td></td>
</tr>
<tr>
<td>“I don’t have the map, I think it’ll be like a map. You get yourself in and then you’ll get to try and find your way out again.”</td>
<td>1:26:49</td>
<td></td>
</tr>
<tr>
<td>“If I don’t have the map, I think it’ll be like a map. You get yourself in and then you’ll get to try and find your way out again.”</td>
<td>1:02:46</td>
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<td>“If I don’t have the map, I think it’ll be like a map. You get yourself in and then you’ll get to try and find your way out again.”</td>
<td>1:03:20</td>
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<tr>
<td>“When I would think to come and look at this house I would want to see the grounds as well, cos that’s part of the whole package sort of thing, that’s what.”</td>
<td>0:17:28</td>
<td></td>
</tr>
<tr>
<td>“At first it seemed as though, like I could only, like, make my way around certain areas.”</td>
<td>1:02:54</td>
<td></td>
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</table>
Issue: The user would like the VE system images to be bigger.

Issue: The user was unsure how to undo an action.
Richard Strauss House (RSH): Deriving Sub-broad Themes from the Thinking-Aloud Protocol Evaluation Data

### Part 36

#### Sub-broad Theme

The combination of the 3D map and the VE is quite good. Destinations and connections are a good combination. If you had to visualize where you were, you wouldn’t get to see the pictures or statues like that.

#### Issues

- You can activate the “Show Hotspots” to show the hotspots.
- The user suggested that there should be more hotspots available especially on how to navigate.
- The user commented that without the option to “show the hotspots” you would not be able to locate the things.
- The experimental tasks and instructions were ambiguous to the user.
- The experimental tasks and instructions were ambiguous to the user.
- The user suggested that there should be more information presented especially on Richard Strauss.
- The user suggested that there should be more hotspots available especially on how to navigate.
- The experimenter suggested that there should be more hotspots available especially on how to navigate.

#### Suggestion: A better way of moving between locations (nodes)

Using the option to move around using the mouse or the VR itself would be preferable.

| P04 | (1:03:05) | About say when we’re out in the grounds, a little bit more, maybe some more detail.
| P06 | (1:09:02 - 1:09:14) | And then um... And then the piano in the task, it says a baby grand piano, but in the instructions it just talks about a grand piano. So they were a little bit confusing.
| P04 | (1:24:40) | The little text sections with the scrolling, Ahm, it’s quite quick, when you’re going down but then all of a sudden, you go for a minute you get your mouse over it, it’s not clear what it is (zoom out using the minus button on the controller). It’s not very clear, so I had to scroll back up again. It’s not very clear, so I had to scroll back up again and quickly out of control just a little bit at a time.
| P04 | (1:31:52) | ...rather than just saying I want to walk here and click something along those lines. Thought that may have been a mask, this must be the area.
| P06 | (0:51:18) | Must be the mask, looking around don’t seem to see anything else. Actually out in the grounds there’s not much here. Just one of the railings, or a little bit of a fence or something along those lines. Thought that may have been a mask, it may be the one near the window, or maybe it’s the one near the top of the indoor glass window (pointing to the indoor glass window). And then, when you click on it, yeah, I don’t get much out of it.
| P07 | (0:24:09) | OK, I think it’s good that it’s got both the map and the window, the VR.

#### EXPERIMENT - COMMENTS

- The user suggested that the VR is so good but it actually doesn’t show me very much at all – the picture presented does not make sense to the user.
- The user commented that the VR system is actually limited in terms of content.
- The user suggested that there should be more hotspots available especially on how to navigate.
- The experimenter suggested that there should be more hotspots available especially on how to navigate.
- The user suggested that there should be more hotspots available especially on how to navigate.
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- The user suggested that there should be more hotspots available especially on how to navigate.

#### EXPERIMENT - SCROLL BARS

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Good: Being able to scroll down some text without clicking on the scroll bar

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Issue: Scroll bars scrolled the text too quickly.

- The experimenter suggested that there should be more hotspots available especially on how to navigate.

#### Good: Text with images is a good combination.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### The combination of the 3D map and the VE is quite good.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### Image quality was poor that it deters and frustrates users from examining objects within the VE system.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

| P04 | (0:59:41) | Having the hot link (rolled over to the “Show Hotspots” icon on the control bar), being able to turn the hotspots on was quite a good idea. If you don’t know the hot spots on it’s quite hard to see where the things are and if you’re scrolling around really fast.
| P04 | (1:00:06) | You kind of zip past them and you don’t realize, see everything looks the same.
| P06 | (1:01:47) | The fact that you can actually move around in good, and the text was also good to give you some idea as to what actually went on, because it’s pretty meaningless. (laugh) Just walking around someone’s house, don’t know why.
| P04 | (1:25:06) | The little text sections with the scrolling, Ahm, it’s quite quick, when you’re going down but then all of a sudden, you go for a minute you get your mouse over it, it’s not clear what it is (zoom out using the minus button on the controller). It’s not very clear, so I had to scroll back up again. It’s not very clear, so I had to scroll back up again and quickly out of control just a little bit at a time.
| P04 | (1:09:02 - 1:09:14) | And... And then the piano in the task, it says a baby grand piano, but in the instructions it just talks about a grand piano. So they were a little bit confusing.
| P04 | (1:23:05) | ...especially on how to navigate.

#### EXPERIMENT - SCROLL BARS

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Good: Text with images is a good combination.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### Issue: Scroll bars scrolled the text too quickly.

- The experimenter suggested that there should be more hotspots available especially on how to navigate.

#### Good: Map and a VR

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### The combination of the 3D map and the VE is quite good.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### Suggestion: A better way of moving between locations (nodes)

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Good: Text with images is a good combination.

- The user suggested that there should be more hotspots available especially on how to navigate.

#### The combination of the 3D map and the VE is quite good.

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Suggestion: A better way of moving between locations (nodes)

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#### Good: Being able to scroll down some text without clicking on the scroll bar

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Issue: Scroll bars scrolled the text too quickly.

- The experimenter suggested that there should be more hotspots available especially on how to navigate.

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- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### The combination of the 3D map and the VE is quite good.

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#### Suggestion: A better way of moving between locations (nodes)

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

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#### The combination of the 3D map and the VE is quite good.

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#### Good: Map and a VR

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### The combination of the 3D map and the VE is quite good.

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.

#### Suggestion: A better way of moving between locations (nodes)

- The user commented that without the option to “show the hotspots” you would not be able to locate the things.
The user does not know what the VE system is doing. There is a lack of feedback to the user especially when loading.

The user does not know how to navigate from one place to another.

The user found that selecting an object on the navigational aid (Map) was a quicker way of navigating between locations.

The user does not have a clear mental idea of how the provided navigational aid (Map) relate to the VE; they are currently in or have visited.

The user is unable to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map).

The user did not expect to travel a great distance when they clicked on a hotspot.

The user found that “jumping” between nodes confusing.

The user found that “jumping” between nodes a waste of time. They prefer a walking effect.

The user is unable to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map).

The user does not have a clear mental idea of how the provided navigational aid (Map) relate to the VE; they are currently in or have visited.

The user was unsure how to undo an action.

The user was unsure if by clicking on an object that a desired result would be the outcome.

The user gets frustrated with the VE system and therefore gives up what they were trying to accomplish.

When an object on the 3D Map is clicked, the user does not realize that the Map Level has changed!

The system functionality was hidden that the user did not realize other places they can navigate to.

The user did not expect to travel a great distance when they clicked on a hotspot.

The user was unsure how to undo an action.

The user was unsure if by clicking on an object that a desired result would be the outcome.

The system functionality was hidden that the user did not realize other functionalities available.

The user explored the functionality of the VE controller buttons were hidden.

The user explored the functionality of the VE controller buttons were hidden.

The user explored the functionality of the VE controller buttons were hidden.

The user explored the functionality of the VE controller buttons were hidden.

The user does not know what the VE system is doing. There is a lack of feedback to the user especially when loading.

The user does not know how to navigate from one place to another.

The user found that selecting an object on the navigational aid (Map) was a quicker way of navigating between locations.

The user does not have a clear mental idea of how the provided navigational aid (Map) relate to the VE; they are currently in or have visited.

The user is unable to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map).

The user did not expect to travel a great distance when they clicked on a hotspot.

The user found that “jumping” between nodes confusing.

The user found that “jumping” between nodes a waste of time. They prefer a walking effect.

The user is unable to determine their spatial orientation (N,S,E,W) with regards to their location on the provided navigational aid (Map).

The user does not have a clear mental idea of how the provided navigational aid (Map) relate to the VE; they are currently in or have visited.
### SOH versus QSC: Deriving Broad Themes from the Think-Aloud Protocol Data

<table>
<thead>
<tr>
<th>SOH Themes</th>
<th>QSC Themes</th>
<th>Sub-Broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXPLORATION</strong> - <strong>SUPPOSING AN ACTION WILL HAVE A CERTAIN RESULT</strong></td>
<td><strong>EXPLORATION</strong> - <strong>SUPPOSING AN ACTION WILL HAVE A CERTAIN RESULT</strong></td>
<td><strong>System Exploration</strong></td>
<td><strong>System Exploration</strong></td>
</tr>
<tr>
<td>The user explores the functionality of the VE system.</td>
<td>The user explores the functionality of the VE system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IMAGE QUALITY</strong></td>
<td><strong>IMAGE QUALITY</strong></td>
<td><strong>VE Image Quality</strong></td>
<td><strong>VE Image Quality</strong></td>
</tr>
<tr>
<td>The overall image quality of the VE is good.</td>
<td>The overall image quality of the VE is good.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>USER EXPECTATION</strong> - <strong>OBJECT BEHAVIOR</strong></td>
<td><strong>USER EXPECTATION</strong> - <strong>OBJECT BEHAVIOR</strong></td>
<td><strong>Real world conventions apply to the VE system</strong></td>
<td><strong>Real world conventions apply to the VE system</strong></td>
</tr>
<tr>
<td>The user expects real world conventions to apply to this VE system.</td>
<td>The user expects real world conventions to apply to this VE system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LOCATION SEARCH</strong></td>
<td><strong>LOCATION SEARCH</strong></td>
<td><strong>Interaction</strong></td>
<td><strong>Interaction</strong></td>
</tr>
<tr>
<td>The user is finding it difficult to locate another location using either the map or the embedded hotspots.</td>
<td>The user is finding it difficult to locate another location using either the map or the embedded hotspots.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INFORMATION SEARCH</strong> - <strong>HELP</strong></td>
<td><strong>INFORMATION SEARCH</strong> - <strong>HELP</strong></td>
<td><strong>Searching for Information and Locations</strong></td>
<td><strong>Searching for Information and Locations</strong></td>
</tr>
<tr>
<td>The user is looking for additional information about a particular location or object but was not available</td>
<td>The user is looking for additional information about a particular location or object but was not available</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INFORMATION PRESENTATION</strong></td>
<td><strong>INFORMATION PRESENTATION</strong></td>
<td><strong>Appearance</strong></td>
<td><strong>Appearance</strong></td>
</tr>
<tr>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user is presented with information that does not clearly tell the user the next step.</td>
<td>The user is presented with information that does not clearly tell the user the next step.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COMMENTS ABOUT VR PRESENTATION</strong></td>
<td><strong>COMMENTS ABOUT VR PRESENTATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During the user's first encounter with the VE system, they found it to be too confusing.</td>
<td>During the user's first encounter with the VE system, they found it to be too confusing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user knows what is in each level but not how they relate to each other.</td>
<td>The user knows what is in each level but not how they relate to each other.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VE PRESENTATION</strong> - <strong>ROBOT</strong></td>
<td><strong>VE PRESENTATION</strong> - <strong>ROBOT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user liked the ability to turn on/off options that you do not like e.g. customise?</td>
<td>The user liked the ability to turn on/off options that you do not like e.g. customise?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>POSITIVE COMMENTS ABOUT THE VR PRESENTATION</strong></td>
<td><strong>POSITIVE COMMENTS ABOUT THE VR PRESENTATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The combination of the 3D map and the VE is quite good.</td>
<td>The combination of the 3D map and the VE is quite good.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user finds that they can see the map and the options with the map.</td>
<td>The user finds that they can see the map and the options with the map.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user found the navigating using the hotspot is much faster and easier to move to a different location.</td>
<td>The user found the navigating using the hotspot is much faster and easier to move to a different location.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user like that they can see both the inside and the outside of the SOH.</td>
<td>The user like that they can see both the inside and the outside of the SOH.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user like that they can see both the inside and the outside of the SOH.</td>
<td>The user like that they can see both the inside and the outside of the SOH.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUCCESSES FOR VR PRESENTATION</strong></td>
<td><strong>SUCCESSES FOR VR PRESENTATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user is suggesting that a feedback aid to other locations have been visited and how to return to them is needed.</td>
<td>The user is suggesting that a feedback aid to other locations have been visited and how to return to them is needed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The navigational aid (EMBEDDED ARROWS) within the VE system need to have a pop-up little windows that state the user's current location, where the link is going to and the nearest exit.</td>
<td>The navigational aid (EMBEDDED ARROWS) within the VE system need to have a pop-up little windows that state the user's current location, where the link is going to and the nearest exit.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The user suggests more system feedback is needed for the VE system.</td>
<td>The user suggests more system feedback is needed for the VE system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EXPERIMENT</strong> - <strong>COMMENTS</strong></td>
<td><strong>EXPERIMENT</strong> - <strong>COMMENTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The experimental tasks and instructions were ambiguous to the user.</td>
<td>The experimental tasks and instructions were ambiguous to the user.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recording of the data using the video camera was unobtrusive.</td>
<td>Recording of the data using the video camera was unobtrusive.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wroxton Abbey (WA) versus Richard Strauss House (RSH): Deriving Broad Themes from the Think-Aloud Protocol Evaluation Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wroxton Abbey Themes</strong></td>
<td><strong>Richard Strauss House Themes</strong></td>
<td><strong>Sub-broad Themes</strong></td>
<td><strong>Broad Themes</strong></td>
</tr>
<tr>
<td><strong>LACK OF FEEDBACK - NO FEEDBACK AS TO HOW THE CURRENT STATE WAS ACHIEVED</strong></td>
<td>The user does not know their current position</td>
<td>The user needs to be able to remember the different location/nodes that they can go to and have been</td>
<td></td>
</tr>
<tr>
<td><strong>LACK OF FEEDBACK - SYSTEM STATE</strong></td>
<td>The user does not know what the VE system is doing. There is a lack of feedback to the user especially when loading.</td>
<td>The user needs to be able to remember the different location/nodes that they can go to and have been</td>
<td></td>
</tr>
<tr>
<td><strong>LACK OF FEEDBACK - MAP</strong></td>
<td>The user is trying to remember where they have been (explored). They wonder why some areas on the map are not accessible (does not have a hotspot). There is no feedback (explanation) as to why this is so.</td>
<td>The user needs to be able to remember where they have been and they do this by remembering numbers on the map rather than what it actually is e.g. No. 5 is the study</td>
<td></td>
</tr>
<tr>
<td><strong>CONTROLLER</strong></td>
<td>The user commented that without the option to &quot;show the hotspots&quot;, the user would not know where they are located and able to click.</td>
<td>The functionality of the VE controller buttons were hidden.</td>
<td></td>
</tr>
<tr>
<td><strong>LIMITED FREEDOM - CONSTRAINT ACCESS</strong></td>
<td>The VE system did not respond as expected to the user's actions.</td>
<td>The user has limited movement/access to places within the VE.</td>
<td></td>
</tr>
<tr>
<td><strong>HIDDEN FUNCTIONALITY</strong></td>
<td>The system functionality was hidden that the user did not realize other functionalities available.</td>
<td>The system functionality was hidden that the user did not realize other functionalities available.</td>
<td></td>
</tr>
<tr>
<td><strong>HIDDEN FUNCTIONALITY - STUCK - NO CLEAR &quot;EMERGENCY&quot; EXITS OR &quot;UNDO&quot; OPTIONS</strong></td>
<td>The user was stuck in a particular location and used an alternative way to exit.</td>
<td>The user was stuck in a particular location and used an alternative way to exit.</td>
<td></td>
</tr>
<tr>
<td><strong>ZOOM IN/OUT - CLOSER LOOK</strong></td>
<td>The functionality to zoom in and out to look in closer detail was hidden from the user.</td>
<td>The functionality to zoom in and out to look in closer detail was hidden from the user.</td>
<td></td>
</tr>
<tr>
<td><strong>The user would like the VE system images to be bigger.</strong></td>
<td>The user would like the VE system images to be bigger.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part 39**
## Wroxton Abbey (WA) versus Richard Strauss House (RSH): Deriving Broad Themes from the Think-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INFORMATION SEARCH - HELP</strong></td>
<td>The user is finding it difficult to locate the answer to an assigned task question</td>
<td>Searching for Information and Locations</td>
</tr>
<tr>
<td><strong>USER EXPECTATION - OBJECT BEHAVIOR</strong></td>
<td>The user expects real world conventions to apply to this VE system</td>
<td><strong>User Expectations</strong></td>
</tr>
<tr>
<td><strong>USER EXPECTATION - NAVIGATION</strong></td>
<td>The user expects the presented object such as when the cursor changes inside the VR to work but there is no feedback as to why it’s not working</td>
<td><strong>User Navigation</strong></td>
</tr>
<tr>
<td><strong>HOTSPOTS/LINKS</strong></td>
<td>The links to the hotspots were not clearly visible so the user clicks on anything within the VE.</td>
<td><strong>Interaction</strong></td>
</tr>
<tr>
<td><strong>NAVIGATION - MOVE FROM ONE PLACE TO ANOTHER</strong></td>
<td>The user did not know how to navigate from one place to another.</td>
<td><strong>User Panning</strong></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The users did not know how to immediately navigate, which leads to confusion as to what is being talked about e.g. piano for Richard Strauss</td>
<td><strong>Navigational Aids</strong></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The user found the panning speed of the VE too fast.</td>
<td><strong>System Exploration</strong></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The navigational aid (Map) provided is incomplete.</td>
<td></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The location of the hotspot was in an unexpected area.</td>
<td></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The user found that selecting an object on the navigational aid (Map) was a quicker way of navigating between locations.</td>
<td></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The map only allows you to move a certain pathway/way/next/previous.</td>
<td></td>
</tr>
<tr>
<td><strong>NAVIGATION /ROTATION - PAN AROUND A LOCATION OR NODE</strong></td>
<td>The user explores the functionality of the VE system - options available.</td>
<td></td>
</tr>
</tbody>
</table>

**Part 40**
# Appendix H: Emergent Themes Analysis of the Thinking-Aloud Protocol Data

## Wroxton Abbey (WA) versus Richard Strauss House (RSH): Deriving Broad Themes from the Think-Aloud Protocol Evaluation Data

<table>
<thead>
<tr>
<th>Wroxton Abbey Themes</th>
<th>Richard Strauss House Themes</th>
<th>Sub-broad Themes</th>
<th>Broad Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information Presentation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
<td>Textual information such as words, icons, symbols and terms were not familiar to the user.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The functions of interaction objects on the VE were not clearly defined.</td>
<td>The way the information was presented to the user was unappealing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The way the information was presented to the user was unappealing.</td>
<td>The way the information was presented to the user was unappealing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Image Quality</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Image quality was poor that it degrades and frustrates users from examining objects within the VE system</td>
<td>Image quality was poor that it degrades and frustrates users from examining objects within the VE system</td>
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<tr>
<td><strong>Comments about the VE presentation</strong></td>
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<tr>
<td>During the user's first encounter with the VE system, they found it to be too confusing.</td>
<td>The user's first encounter with the VE system, they found it to be too confusing.</td>
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<tr>
<td>The user's first encounter with the VE system, they found it to be too confusing.</td>
<td>The user's first encounter with the VE system, they found it to be too confusing.</td>
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<tr>
<td><strong>VE Presentation - Scroll Bars</strong></td>
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<tr>
<td>The interaction object (SCROLL BARS) were moving the text too fast.</td>
<td>The interaction object (SCROLL BARS) were moving the text too fast.</td>
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</tr>
<tr>
<td><strong>Positive Comments About the VE Presentation</strong></td>
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<tr>
<td>The user found the navigating using the hotspot is much faster and easier to move to a different location.</td>
<td>The user found the navigating using the hotspot is much faster and easier to move to a different location.</td>
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</tr>
<tr>
<td>The overall image quality of the VE is good.</td>
<td>The overall image quality of the VE is good.</td>
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<tr>
<td>The user commented that without the option to &quot;show the hotspots&quot;, the user would not know where they are located and able to click.</td>
<td>The user commented that without the option to &quot;show the hotspots&quot;, the user would not know where they are located and able to click.</td>
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<tr>
<td>The user commented that they liked that they can pan around a location.</td>
<td>The user commented that they liked that they can pan around a location.</td>
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<tr>
<td>The user commented on how they felt about using the VE</td>
<td>The user commented on how they felt about using the VE.</td>
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<tr>
<td>Good: Text with images is a good combination</td>
<td>Good: Text with images is a good combination</td>
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<tr>
<td>The combination of the 3D map and the VE is quite good</td>
<td>The combination of the 3D map and the VE is quite good.</td>
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</tr>
<tr>
<td>The user commented that without the option to &quot;show the hotspots&quot;, the user would not know where they are located and able to click.</td>
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</tr>
<tr>
<td>Automation of some interaction objects (SCROLL BARS) are actually good.</td>
<td>Automation of some interaction objects (SCROLL BARS) are actually good.</td>
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</tr>
<tr>
<td>Option to navigate using the map or the embedded hotspot</td>
<td>Option to navigate using the map or the embedded hotspot</td>
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<tr>
<td><strong>Suggestions for VR Presentation Improvement</strong></td>
<td></td>
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<tr>
<td>The user is suggesting that a better way to navigate between the nodes/locations would be better such as a drop-down list or a combo box.</td>
<td>The user is suggesting that a better way to navigate between the nodes/locations would be better such as a drop-down list or a combo box.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system functionality should be more visible especially on how to navigate.</td>
<td>The system functionality should be more visible especially on how to navigate.</td>
<td></td>
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</tr>
<tr>
<td>The user suggested that there should be more hotspots available e.g. outside the WA.</td>
<td>The user suggested that there should be more hotspots available e.g. outside the WA.</td>
<td></td>
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<tr>
<td>The user suggested that they should have the flexibility to use both the keyboard and the mouse to navigate within the VE system.</td>
<td>The user suggested that they should have the flexibility to use both the keyboard and the mouse to navigate within the VE system.</td>
<td></td>
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<tr>
<td>The system functionality should be more visible especially on how to navigate.</td>
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<tr>
<td>The user suggested that there should be more hotspots available e.g. outside the RSH.</td>
<td>The user suggested that there should be more hotspots outside the RSH.</td>
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<tr>
<td>The user suggested that more system feedback is needed for this VE system.</td>
<td>The user suggested that more system feedback is needed for this VE system.</td>
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</tr>
<tr>
<td>The navigational aid (EMBEDDED ARROWS) within the VE system need to have a pop-up title windows that state the user's current location, the link is going to and the nearest exit.</td>
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<td></td>
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</tr>
<tr>
<td>The user suggested that there should be a clearer link between the navigational aid (EMBEDDED ARROWS) within the VE. The tooltip that popup should not cover the VE.</td>
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<td></td>
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</tr>
<tr>
<td>The user suggested that the navigational aid (Map) provided should be at the same level as the VE window.</td>
<td>The user suggested that the navigational aid (Map) provided should be at the same level as the VE window.</td>
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</tr>
<tr>
<td>The user suggested that when providing a navigational aid image that it should be more detailed.</td>
<td>The user suggested that when providing a navigational aid image that it should be more detailed.</td>
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</tr>
<tr>
<td>The user suggested that there should be a quicker way of navigating such as a drop-down list or combo box.</td>
<td>The user suggested that there should be a quicker way of navigating such as a drop-down list or combo box.</td>
<td></td>
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</tr>
<tr>
<td>The user suggested that perhaps an audio guide would better enhance the VE experience.</td>
<td>The user suggested that perhaps an audio guide would better enhance the VE experience.</td>
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<tr>
<td>The user suggested that a more powerful zoom would allow the user to look farther into the area.</td>
<td>The user suggested that a more powerful zoom would allow the user to look farther into the area.</td>
<td></td>
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<tr>
<td>The user suggested that perhaps different perspectives of the same location can be made available to the users.</td>
<td>The user suggested that perhaps different perspectives of the same location can be made available to the users.</td>
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<tr>
<td><strong>Experiment - Comments</strong></td>
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<tr>
<td>The order of the testing was good. Exploration of the system and then performance of the tasks.</td>
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</tbody>
</table>

WA versus RSH: Deriving Broad Themes from the Think-Aloud Protocol Data

Part 41