

Cox, Christopher (2003) The use of computer graphics and virtual reality for visual impact assessments. PhD thesis, University of Nottingham.

Access from the University of Nottingham repository:
http://eprints.nottingham.ac.uk/10038/1/Whole_Thesis.pdf

Copyright and reuse:

The Nottingham ePrints service makes this work by researchers of the University of Nottingham available open access under the following conditions.

- Copyright and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners.
- To the extent reasonable and practicable the material made available in Nottingham ePrints has been checked for eligibility before being made available.
- Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.
- Quotations or similar reproductions must be sufficiently acknowledged.

Please see our full end user licence at:
http://eprints.nottingham.ac.uk/end_user_agreement.pdf

A note on versions:

The version presented here may differ from the published version or from the version of record. If you wish to cite this item you are advised to consult the publisher's version. Please see the repository url above for details on accessing the published version and note that access may require a subscription.

For more information, please contact eprints@nottingham.ac.uk

University of Nottingham
School of Chemical, Environmental and Mining Engineering



**The Use of Computer Graphics and Virtual Reality
for Visual Impact Assessments**

by Christopher Cox, BEng

Thesis submitted to the University of Nottingham
for the degree of Doctor of Philosophy, May 2003

Table of Contents

Abstract.....	ix
Acknowledgements	x
Acronym Page.....	xi
List of Figures.....	xii
List of Tables.....	xvi
List of Graphs	xvii
1 Introduction	1
1.1 Introduction To Thesis	1
1.2 Aims of the Research	3
1.3 Overview of Thesis	3
2 Computer Graphics and Virtual Reality.....	5
2.1 Introduction to Computer Graphics.....	5
2.1.1 Definition.....	5
2.1.2 Development of Computer Graphics	5
2.1.3 Applications of Computer Graphics	7
2.1.3.1 Engineering, Design and Visualisation.....	7
2.1.3.2 Accident Reconstruction.....	8
2.1.3.3 Education and Training	10
2.1.3.4 Entertainment	11
2.1.3.5 Medicine.....	12
2.1.3.6 Art	13
2.1.3.7 Data Visualisation	13
2.1.4 Software.....	15
2.1.4.1 Image Editing	15
2.1.4.2 Computer Aided Design.....	15
2.1.4.3 3D Modelling and Animation.....	16
2.1.4.4 Geographical Information Systems	18
2.2 Theory of Computer Graphics.....	18
2.2.1 Bitmap Images.....	19
2.2.2 The RGB Colour Model.....	22
2.2.3 Basic 3D Modelling Concepts.....	24
2.2.3.1 Co-ordinate Systems	24
2.2.3.2 Points, Lines and Faces	25
2.2.3.3 Geometric Transformations.....	26
2.2.3.4 Digital Elevation and Terrain Models	27
2.2.4 Lights, Cameras and Shading and Surface Characteristics.....	27

2.2.4.1	Lighting and Shadows	27
2.2.4.2	Cameras	30
2.2.4.3	Surface Shading Techniques	30
2.2.4.4	Image Mapping	31
2.2.5	3D Animation	33
2.2.5.1	Units of Animation and Animation Compression Techniques	33
2.2.5.2	Keyframing	34
2.2.5.3	Motion Paths	35
2.2.5.4	Hierarchies and Kinematics	35
2.2.6	Rendering	38
2.2.6.1	The Rendering Process	38
2.2.6.2	Rendering Techniques	38
2.2.6.3	Rendering Options	39
2.3	Example 3D Model	40
2.3.1	Modelling the Geometry	41
2.3.1.1	Basic Geometry	41
2.3.1.2	Editing the Geometry	42
2.3.2	Shading	42
2.3.3	Lighting and Shadows	42
2.4	Introduction to Virtual Reality	43
2.4.1	Definition	43
2.4.2	History of Virtual Reality	44
2.4.3	Types of Virtual Reality Systems	45
2.4.3.1	Simulation Systems	45
2.4.3.2	Immersion Systems	46
2.4.3.3	Projection Systems	46
2.4.3.4	Desktop Systems	47
2.4.3.5	Augmented Reality	47
2.4.4	Applications of Virtual Reality	48
2.4.4.1	Medicine	49
2.4.4.2	Education and Training	50
2.4.4.3	Entertainment and Sport	51
2.4.4.4	Engineering and Architecture	52
2.4.4.5	Data Visualisation	53
2.4.5	Virtual Reality Software	54
2.4.5.1	Free of Charge Software	54
2.4.5.2	Inexpensive Software	55
2.4.5.3	Moderately Expensive Software	55
2.4.5.4	Expensive Software	55
2.4.6	Benefits and Limitations of Virtual Reality	56
2.4.6.1	Benefits	56
2.4.6.2	Limitations	57
2.5	Virtual Reality Example	57
2.5.1	Importing Objects	58
2.5.2	Interaction with Objects	59
2.5.3	Creating Hazards	60
2.6	Summary	61
3	Assessing Environmental and Visual Impact	62
3.1	Environmental Impact Assessment	62
3.1.1	Introduction	62
3.1.2	Current Legislation	63

3.1.3	The Environmental Impact Assessment Process.....	65
3.1.3.1	Considerations of Alternatives.....	66
3.1.3.2	Screening.....	66
3.1.3.3	Scoping.....	66
3.1.3.4	Baseline Study.....	67
3.1.3.5	Impact Prediction, Assessment and Mitigation.....	67
3.1.3.6	Production of an Environmental Impact Statement.....	68
3.1.3.7	Review of Environmental Impact Statement.....	69
3.1.3.8	Monitoring and Auditing.....	69
3.2	Leavesden Park – An Example EIA Statement.....	70
3.2.1	Introduction.....	70
3.2.2	Environmental Issues.....	72
3.2.3	Conclusion of EIA for Leavesden Park.....	72
3.3	Visual Impact Assessment.....	73
3.3.1	Introduction.....	73
3.3.2	Legislation.....	75
3.3.3	The Visual Impact Assessment Process.....	76
3.3.3.1	Description of the Development and Considerations of Alternatives.....	76
3.3.3.2	Baseline Studies.....	76
3.3.3.3	Potential Impacts, Magnitude and Significance.....	77
3.3.3.4	Mitigation.....	79
3.3.3.5	Presentation of Findings.....	80
3.3.3.6	Consultation, Review and Implementation.....	80
3.3.4	Current Visual Impact Assessment Techniques.....	81
3.3.4.1	Fields of Visual Influence.....	83
3.3.4.2	Helium Balloons.....	86
3.3.4.3	Percentage View Changes.....	87
3.3.4.4	Solid Angles and Vertical Fields of View.....	89
3.3.4.5	Landscape Evaluation.....	91
3.3.4.6	Number of Targets Seen, Descriptive Statements, Checklists and Matrices.....	92
3.3.4.7	Physical Scaled Model.....	93
3.3.4.8	Perspective Views.....	94
3.3.4.9	Photomontages.....	96
3.3.4.10	Computer Generated Animations.....	99
3.3.4.11	Virtual Reality.....	100
3.4	Factors Affecting Visual Impact Assessment.....	101
3.4.1	Surveying 3D Baseline Data.....	101
3.4.1.1	Manual Surveying.....	101
3.4.1.2	Laser Scanning.....	101
3.4.1.3	DEM Accuracy.....	103
3.4.2	Earth Curvature and Atmospheric Refraction.....	104
3.4.3	Seasonal Variation and Growth of Vegetation.....	107
3.5	Summary.....	108
4	Current Use of Computer Graphics and Virtual Reality for Visual Impact Assessment.....	109
4.1	Introduction.....	109
4.2	Virtual Los Angeles Project.....	109
4.2.1	Introduction.....	109
4.2.2	Methodology.....	110
4.2.3	Analysis.....	111

4.3	LSS Terrain Modelling System.....	112
4.3.1	Introduction.....	112
4.3.2	Fields of Visual Influence.....	112
4.3.3	Vertical Angles.....	113
4.3.4	Number of Targets Seen.....	113
4.3.5	Virtual Reality Simulations.....	114
4.3.6	Analysis	114
4.4	LandScape Information System	115
4.4.1	Introduction.....	115
4.4.2	LSIS Database.....	116
4.4.3	Fields of Visual Influence and Visualisations	117
4.4.4	Analysis	118
4.5	ArcView	118
4.5.1	Introduction.....	118
4.5.2	Fields of Visual Influence.....	119
4.5.3	Analysis	120
4.6	GIS Based Augmented Reality	121
4.6.1	Introduction.....	121
4.6.2	Methodology	121
4.6.3	Analysis	123
4.7	GIS Based Virtual Reality.....	124
4.7.1	Introduction.....	124
4.7.2	Methodology	124
4.7.3	Analysis	126
4.8	German Railway Project	127
4.8.1	Introduction.....	127
4.8.2	Data Acquisition	127
4.8.3	3D Modelling and Texturing.....	129
4.8.4	Analysis	131
4.9	Summary	132
5	Development of New Techniques	135
5.1	Introduction.....	135
5.2	Field of Visual Influence Technique	135
5.2.1	Introduction.....	135
5.2.2	Methodology	135
5.2.2.1	Reflective Field of Visual Influence	137
5.2.2.2	Cumulative Reflective Field of Visual Influence.....	141
5.2.2.3	Projective Field of Visual Influence.....	143
5.2.2.4	Cumulative Projective Field of Visual Influence.....	144
5.2.3	Dene Quarry - Field of Visual Influence Example	146
5.2.4	Analysis	149
5.3	Percentage View Change Analysis	150
5.3.1	Introduction.....	150
5.3.2	Methodology	150

5.3.3	Road Sign Visibility Example	157
5.3.4	Analysis	159
5.4	Earth Curvature and Atmospheric Refraction.....	160
5.4.1	Introduction.....	160
5.4.2	Methodology	161
5.4.3	Analysis	165
5.5	Seasonal Variation and Growth of Vegetation.....	166
5.5.1	Introduction.....	166
5.5.2	Methodology	166
5.5.3	Analysis	172
5.6	Virtual Reality Techniques.....	173
5.6.1	Introduction.....	173
5.6.2	An Integrated Approach Using Safe-VR.....	174
5.6.2.1	Methodology	174
5.6.2.2	Analysis.....	176
5.6.3	An Integrated Approach Using Director	177
5.6.3.1	Methodology	177
5.6.3.2	Analysis.....	180
5.7	Summary	181
6	Case Studies	183
6.1	Introduction.....	183
6.2	Stoke Approach Corridor Study.....	183
6.2.1	Introduction.....	183
6.2.2	Data Acquisition	185
6.2.3	Modelling.....	186
6.2.4	Animations.....	192
6.2.5	Percentage View Change Analysis	192
6.2.6	Analysis	195
6.3	Birmingham University Hospital Case Study.....	195
6.3.1	Introduction.....	195
6.3.2	Data Acquisition.....	198
6.3.3	Development Of The New University Hospital.....	200
6.3.3.1	Modelling.....	200
6.3.3.2	Visualisations.....	205
6.3.3.3	Percentage View Change Analysis	206
6.3.3.4	Integrated Visual Impact Assessment Using Virtual Reality.....	210
6.3.4	Relocation of the Psychiatric Hospital.....	213
6.3.4.1	Modelling.....	213
6.3.4.2	Visualisations.....	216
6.3.4.3	Percentage View Change Analysis	217
6.3.5	Analysis	222
6.4	Bellmoor Quarry, Tiln South.....	223
6.4.1	Introduction.....	223
6.4.2	Data Acquisition	224
6.4.3	Modelling.....	226

6.4.3.1	Pre-Development Model.....	226
6.4.3.2	During Quarrying Model.....	231
6.4.3.3	Post-development Model.....	233
6.4.4	Visualisations using Rendered Images and Animations	235
6.4.5	Fields of Visual Influence.....	237
6.4.6	Percentage View Change Analysis	243
6.4.7	Seasonal Variation	252
6.4.8	Integrated Visual Impact Assessment Using Virtual Reality.....	257
6.4.9	Analysis	262
6.5	Summary	264
7	Conclusions and Recommendations	267
7.1	Introduction.....	267
7.2	Overview of Thesis	268
7.3	Conclusions	271
7.3.1	Problems With Existing Visual Impact Assessment Techniques	271
7.3.2	Development of New and Enhanced Techniques.....	274
7.3.2.1	Fields of Visual Influence.....	274
7.3.2.2	Percentage View Change Analysis.....	275
7.3.2.3	Virtual Reality.....	275
7.3.2.4	Effects of Earth Curvature and Atmospheric Refraction.....	276
7.3.2.5	Seasonal Variation and Growth of Vegetation.....	277
7.3.3	Problems With New and Enhanced Techniques.....	277
7.3.3.1	Fields of Visual Influence.....	277
7.3.3.2	Percentage View Change Analysis.....	278
7.3.3.3	Virtual Reality.....	279
7.3.3.4	Effects of Earth Curvature and Atmospheric Refraction.....	279
7.3.3.5	Seasonal Variation and Growth of Vegetation.....	280
7.4	Recommendations	280
7.5	Concluding Remarks.....	281
8	References.....	282
Appendix 1: Software Used.....	300	
A1.1	Introduction.....	300
A1.2	AutoCAD	300
A1.3	3D Studio MAX	300
A1.3.1	MAXScripting.....	301
A1.3.2	Forest Pro Plug-in.....	302
A1.4	Paint Shop Pro.....	303
A1.5	Safe-VR.....	303
A1.6	Director 8.5 Shockwave Studio.....	305

A1.7	CorelDRAW	306
Appendix 2: Hardware Used.....		308
A2.1	Introduction.....	308
A2.2	Required Hardware	308
Appendix 3: Morpeth Flood Visualisation.....		310
A3.1	Introduction.....	310
A3.2	Methodology	311
A3.3	Analysis.....	313
Appendix 4: AIMS Solutions Leaflets		314
Appendix 5: Bitmap Colour Counter MAXScript		315
Appendix 6: Earth Curver MAXScript		319
Appendix 7: Birmingham University Hospital		321
A7.1	Visualisations Of The New University Hospital.....	321
A7.2	Visualisations Of the Psychiatric Hospital.....	325
Appendix 8: Bellmoor Quarry, Tilm South.....		331
A8.1	Rendered Images From Critical Viewpoints During The Summer.....	331
A8.2	Fields of Visual Influence	338
A8.3	Rendered Images From Critical Viewpoints During The Winter	344
Appendix 9: CD-ROM.....		351

Abstract

Changes to the visual character of the landscape can become a key issue capable of influencing the outcome of an Environmental Impact Assessment (EIA). These changes are commonly referred to as visual impact, and it is recognised, unlike many other aspects of EIAs, that Visual Impact Assessment (VIA) relies less upon measurement than upon experience and judgement (IEATLI, 1995). Currently, there are very few quantitative techniques for the evaluation of visibility and it is mostly assessed qualitatively since it is concerned with the human appreciation of the landscape (Zewe and Koglin, 1995 and Wherrett, 2002). The main problem with qualitative techniques in assessing visual impact is that they may lead to bias due to their inherent subjectivity, hence there is a need for a more structured and consistent approach towards VIA.

To reduce the subjectivity currently associated with VIAs, new quantitative techniques have been developed and existing spatial and qualitative techniques have been improved upon. The techniques developed in this research use Computer Graphics (CG) technology, including the field of Virtual Reality (VR).

A quantitative method to calculate percentage view change has been developed that allows the accurate determination of the variation in any view, caused by an existing or proposed development. The method uses three dimensional (3D) CG models of an environment and software that has been developed using a scripting language from a 3D modelling software package. A new method has also been developed to create Fields of Visual Influence (FVIs) using standard 3D modelling techniques. The method improves upon the accuracy and efficiency of existing FVI techniques. A novel VR simulation technique has also been developed that attempts to reduce the subjectivity associated with simulations, by integrating quantitative and spatial techniques.

Acknowledgements

The author would like to express his sincere thanks to the following:

The University of Nottingham and **EPSRC** for the funding during the duration of this research study.

Dr. Damian Schofield for his supervision and input, and his help and continued support throughout the duration of this work.

Babtie Group for the funding and provision of suitable case studies for this research.

Everyone at the **AIMS Research Unit** and **AIMS Solutions** for their help with this research and the use of their facilities.

My deepest thanks go to all of my **family**, particularly my **parents**, and to my fiancée **Becky**, who have provided a great deal of support, advice, and encouragement.

Acronym Page

2D	Two Dimensional
3D	Three Dimensional
BMP	Bitmap
CAD	Computer Aided Design
CADAM	Computer Aided Design and Manufacturing
CFD	Computational Fluid Dynamics
CG	Computer Graphics
CMYK	Cyan, Magenta, Yellow, Black
CRT	Cathode Ray Tube
DEM	Digital Elevation Model
DOEWO	Department of the Environment Welsh Office
DTM	Digital Terrain Model
DVD	Digital Versatile Disc
EC	European Communities
ECW	Enhanced Compressed Wavelet
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EU	European Union
FVI	Field of visual influence
GIF	Graphics Interchange Format
GIS	Geographical Information System
GPS	Global Positioning System
HMD	Head Mounted Display
IEATLI	Institute of Environmental Assessment and The Landscape Institute
JPEG	Joint Photographics Experts Group
LITIEMA	The Landscape Institute and the Institute of Environmental Management and Assessment
LSIS	LandScape Information System
MRI	Magnetic Resonance Imaging
NCDOT	North Carolina Department of Transportation
NTS	Non-Technical Summary
NURBS	Non-Uniform Rational B-Splines
OS	Ordnance Survey
PC	Personal Computer
PDA	Personal Digital Assistant
PNG	Portable Network Graphics
RGB	Red, Green, Blue
SBE	Scenic Beauty Estimation
SGI	Silicon Graphics, Inc.
TGA	Truevision Targa
TIFF	Tagged Image File Format
UK	United Kingdom
VIA	Visual Impact Assessment
VMS	Visual Management System
VR	Virtual Reality
VRML	Virtual Reality Modelling Language

List of Figures

Figure 2.1: Typical CAD software package interface.....	8
Figure 2.2: Perspective view of an accident reconstruction.....	9
Figure 2.3: Rendered image from Safe Driver, a CG safety training application.....	10
Figure 2.4: Image from Pixar’s Toy Story.....	11
Figure 2.5: A 3D model of a human lower arm.....	12
Figure 2.6: A typical logo created using a CG software package.....	13
Figure 2.7: A cloud of particles representing noise levels through their colour and size.....	14
Figure 2.8: Screenshot of 3D Studio MAX.....	17
Figure 2.9: Example of a bitmap image illustrating its individual pixels.....	19
Figure 2.10: Compressed versus uncompressed (left and right respectively).....	21
Figure 2.11: The effect of anti-aliasing (applied to image on right).....	22
Figure 2.12: Additive RGB model and subtractive CMYK model.....	23
Figure 2.13: Co-ordinate system.....	25
Figure 2.14: Example of a 3D triangulated face.....	26
Figure 2.15: Examples of light sources.....	28
Figure 2.16: Anchoring effect of shadows.....	29
Figure 2.17: Different shading types.....	31
Figure 2.18: The use of image mapping.....	32
Figure 2.19: The use of procedural bump maps.....	32
Figure 2.20: The use of keyframes for animating.....	34
Figure 2.21: The use of a motion path to define a car’s position through time.....	35
Figure 2.23: Example hierarchy of the human leg.....	37
Figure 2.24: A bedroom scene modelled using 3D Studio MAX.....	40
Figure 2.25: Step by step process of creating lamp model.....	41
Figure 2.26: Rendered image of finished lamp model.....	43
Figure 2.27: Screenshot of Return to Castle Wolfenstein.....	44
Figure 2.29: A typical HMD.....	46
Figure 2.30: Augmented reality image of underground pipes and cables.....	48
Figure 2.31: Simulated augmented reality medical image.....	49
Figure 2.32: Absorption column VR simulation trainer.....	50
Figure 2.33: VR golf simulator.....	51
Figure 2.34: Architectural walkthrough of a studio.....	52
Figure 2.35: VR visualisation of smoke from a burning car.....	53
Figure 2.36: VR kitchen with a number of hazards.....	58
Figure 2.37: Safe-VR simulation modules.....	59
Figure 2.38: Hazard spotting.....	60
Figure 3.1: EIA process.....	65
Figure 3.2: The Gaussian Dispersion Model.....	68
Figure 3.3: Proposals for Leavesden Park.....	71
Figure 3.4: Examples of qualitative and quantitative standards.....	75
Figure 3.5: Sensitivity of some common visual receptors.....	78
Figure 3.6: A radial line FVI with red areas indicating visibility.....	84
Figure 3.7: An FVI with boxes representing the number of visible targets.....	86
Figure 3.8: A solid angle.....	90
Figure 3.9: A physical scaled model of the Jubilee campus, Nottingham.....	93
Figure 3.10: Computer simulated perspective view of proposed woodland planting.....	95
Figure 3.11: Hand painted photomontage.....	96
Figure 3.12: A photomontage of a combined-cycle gas turbine power station.....	98
Figure 3.13: Examples of DTMs created by airborne laser scanning.....	102
Figure 3.14: Typical long range laser scanner.....	103
Figure 3.15: Equation for the elevation loss due to atmospheric refraction and earth curvature.....	104
Figure 3.16: Equation for the elevation loss due to atmospheric refraction and earth curvature.....	104
Figure 3.17: Elevation loss due to earth curvature and gain due to atmospheric refraction.....	105
Figure 3.18: Equation for the elevation loss due to atmospheric refraction and earth curvature.....	105
Figure 3.19: Equation for the elevation loss due to atmospheric refraction and earth curvature.....	106
Figure 3.20: Photomontages showing vegetative growth over time.....	107
Figure 4.1: Downtown Los Angeles VR model.....	110

Figure 4.2:	Radial lines indicate which objects are visible from a selected viewpoint.....	113
Figure 4.3:	3D Vantage Interface.	114
Figure 4.4:	FVI of a proposed project.	117
Figure 4.5:	Photomontage of proposed development.	117
Figure 4.6:	A cumulative projective FVI of a quarry.....	120
Figure 4.7:	The three video sequences (top) are composited to produce a single sequence (bottom).	122
Figure 4.8:	Screenshot of a weed spread model within ArcGIS.	123
Figure 4.9:	Image of the Cudgewa Valley.....	125
Figure 4.10:	The ArcGIS interface.	125
Figure 4.11:	Image of Cudgewa Valley with a forest selected as an alternative land cover type.	126
Figure 4.12:	Laser scan point cloud and the ortho-rectified aerial image of the proposed site.	128
Figure 4.13:	3D wireframe surface terrain mesh.	128
Figure 4.14:	Rendered image of the German railway.	130
Figure 4.15:	Rendered image from a critical viewpoint.	131
Figure 5.1:	View of car from a selected viewpoint.	137
Figure 5.2:	Basic FVI produced by rendering plan view of scene (a) and manipulated FVI (b).	138
Figure 5.3:	Plan view of the German railway environment.....	139
Figure 5.4:	Rendered plan image with a single omni light positioned at selected viewpoint.....	139
Figure 5.5:	FVI resulting from the viewpoint indicated by the yellow dot.....	140
Figure 5.6:	Panoramic view of German railway environment.	141
Figure 5.7:	Cumulative FVI produced using two omni lights simultaneously.....	142
Figure 5.8:	Cumulative FVI produced by combining two individual FVIs.	142
Figure 5.9:	A projective FVI initiated from a point on the car shown by the yellow marker.	143
Figure 5.10:	Rendered image of the proposed railway structure.	144
Figure 5.11:	The positioning of omni lights to produce a projective FVI.....	145
Figure 5.12:	Projective FVI for the structure shown in yellow.....	145
Figure 5.13:	3D model of Dene Quarry and surrounding environment.....	146
Figure 5.14:	Placement of the omni lights around the quarry perimeter.	147
Figure 5.15:	FVI for Dene Quarry.	148
Figure 5.16:	3D FVI of Dene Quarry.	148
Figure 5.18:	Flowchart of the percentage view change technique.....	152
Figure 5.19:	Example text file output from the Bitmap Colour Counter.....	154
Figure 5.20:	Example spreadsheet output from a Bitmap Colour Counter text file.	154
Figure 5.21:	Rendered image from the original 3D environment.....	155
Figure 5.22:	Rendered image from the modified 3D CG environment.	156
Figure 5.23:	Rendered image of the road sign visibility 3D CG model.	157
Figure 5.24:	Poor visibility of the road signs.....	158
Figure 5.25:	Good visibility of the road signs.....	158
Figure 5.26:	Modified images of the poor (left) and good (right) visibility scenario viewpoints.....	159
Figure 5.28:	Original surface (a) and the curved surface (b).....	162
Figure 5.29:	View of proposed development before ground has been curved.....	163
Figure 5.30:	Modified view of proposed development before ground has been curved.....	163
Figure 5.31:	Summer tree bitmap (left) and a winter tree bitmap (right).	167
Figure 5.32:	Summer tree opacity bitmap (left) and the winter tree opacity bitmap (right).	167
Figure 5.33:	Tree model with opacity map (left) and tree model with no opacity map (right).	168
Figure 5.34:	Farmhouse overlooking proposed development.	168
Figure 5.35:	Summer view of proposed development.....	170
Figure 5.36:	Winter view of proposed development.....	170
Figure 5.37:	Summer (a) and winter (b) images from the Bitmap Colour Counter utility.....	171
Figure 5.38:	Dene Quarry environment before quarrying.....	174
Figure 5.39:	Dene Quarry environment during (left) and after (right) quarrying.	175
Figure 5.40:	FVI draped over the 3D terrain surface.	175
Figure 5.41:	Percentage view change results superimposed over house windows.....	176
Figure 5.42:	Real-Time PVA Simulation interface.	178
Figure 5.43:	Photograph of Dene Quarry shown within Real-Time PVA Simulation.....	179
Figure 5.44:	Alternate model used for determining the percentage view.....	180
Figure 6.1:	The Hartshill area.....	184
Figure 6.2:	Photographs from the key viewing location.	184
Figure 6.3:	Rendered image of proposed landscape beacon.....	185
Figure 6.4:	Contour splines for the Hartshill area.	186

Figure 6.5: Foreground image.....	188
Figure 6.6: Foreground mask.....	188
Figure 6.7: Rendered image of the Hartshill area before development.....	188
Figure 6.8: Landscape beacon models.....	189
Figure 6.9: The beacon bridge photomontage.....	190
Figure 6.10: Stages in modelling the Beacon bridge.....	190
Figure 6.11: Part of the elevated walkway of the pedestrian and cycle link.....	191
Figure 6.12: Rendered image of Hartshill area from selected viewpoint post-development.....	191
Figure 6.13: Rendered image from the colour modified pre-development model.....	193
Figure 6.14: Rendered image from the colour modified post-development model.....	194
Figure 6.15: Aerial view of proposed site.....	197
Figure 6.16: Example of digital CAD data showing the location of various vegetative species.....	199
Figure 6.17: Digital CAD data showing one of the proposed psychiatric buildings.....	199
Figure 6.18: Surface terrain mesh. Detailed 2m contours can be seen in the centre of the mesh.....	200
Figure 6.19: CAD plan, sketch drawing and rendered image of the new university hospital.....	202
Figure 6.20: Location and direction of critical viewpoints.....	203
Figure 6.21: Rendered image of the proposed university hospital site before development.....	204
Figure 6.22: Rendered image of the proposed university hospital site post-development.....	204
Figure 6.23: Photomontage from critical viewpoint two showing the proposed university hospital.....	205
Figure 6.24: Colour modified image from critical viewpoint two after the hospital development.....	207
Figure 6.25: View of the tower block showing the percentage view decrease in vegetation.....	209
Figure 6.26: View of the tower block showing the percentage view of the proposed hospital.....	209
Figure 6.27: Double plane tree model.....	211
Figure 6.28: Safe-VR simulation view from critical viewpoint one.....	212
Figure 6.29: View of the tower block showing the percentage view of the proposed hospital.....	212
Figure 6.30: Rendered image of the new psychiatric hospital.....	213
Figure 6.31: Rendered image of the psychiatric hospital site pre-development.....	214
Figure 6.32: Rendered image of the psychiatric hospital site post-development.....	214
Figure 6.33: Location and direction of critical viewpoints.....	215
Figure 6.34: Rendered image of the psychiatric hospital site post-development.....	216
Figure 6.35: Colour modified image from critical viewpoint three showing the psychiatric hospital.....	218
Figure 6.36: View of the tower block showing the percentage view decrease in vegetation.....	221
Figure 6.37: View of the tower block showing the percentage view of the psychiatric hospital.....	221
Figure 6.38: Aerial photograph of proposed site situated near Tiln South.....	224
Figure 6.39: Pre-development CAD data of Tiln South in an annotated printed format.....	225
Figure 6.40: Contour and land use splines generated from printed CAD data (as shown in figure 6.39).	225
Figure 6.41: Contour splines for the pre-development model.....	227
Figure 6.42: 3D textured ground surface of the pre-development model.....	227
Figure 6.43: Modelling process of the electricity pylon.....	228
Figure 6.44: Rendered image of a 3D hedge model.....	229
Figure 6.45: Reflection and bump map applied to an extruded spline to simulate the river.....	229
Figure 6.46: Rendered images of the model with an illegible road (a) and modelled road (b).	230
Figure 6.47: Rendered image of Tiln South and proposed quarry site pre-development.....	231
Figure 6.48: Surface texture for the during quarrying model.....	232
Figure 6.49: Rendered image of Tiln South and proposed quarry site during quarrying.....	233
Figure 6.50: Surface texture for the post-development model.....	234
Figure 6.51: Rendered image of Tiln South and proposed quarry site post-development.....	234
Figure 6.52: Location of critical viewpoints identified by white ring.....	235
Figure 6.53: Critical viewpoint one pre-development.....	236
Figure 6.54: Critical viewpoint one during quarrying.....	236
Figure 6.55: Critical viewpoint one post-development.....	237
Figure 6.56: Black and white FVI for critical viewpoint one pre-development.....	238
Figure 6.57: FVI for critical viewpoint one pre-development.....	239
Figure 6.58: Cumulative FVI for the pre-development model at Tiln South.....	240
Figure 6.59: Cumulative FVI for the quarrying phase of Bellmoor quarry.....	241
Figure 6.60: Cumulative FVI for the proposed reclamation of Bellmoor quarry.....	242
Figure 6.61: Colour modified image of the during quarrying model from critical viewpoint one.....	244
Figure 6.62: Location of road along which animation was performed.....	249
Figure 6.63: Selection of summer and winter tree textures.....	252

Figure 6.64: Rendered view from critical viewpoint two during the quarrying stage.....	253
Figure 6.65: Critical viewpoint two during the quarrying stage of the winter colour modified model....	254
Figure 6.66: Tltn South Real-Time PVA Simulation interface.....	258
Figure 6.67: Tltn South Real-Time PVA Simulation interface displaying the colour modified model...	259
Figure 6.68: Tltn South Real-Time PVA Simulation interface showing an FVI.....	259
Figure 6.69: Tltn South Real-Time PVA Simulation “motion” interface.	260

List of Tables

Table 2.1: Common file types and some of their advantages and disadvantages.....	21
Table 2.2: RGB settings for the standard white light colour spectrum.	23
Table 2.3: Terms to describe hierarchies (adapted from Schofield, 2000).	36
Table 3.1: Current land use for Leavesden Park.	70
Table 3.2: Proposed land use for Leavesden Park.	71
Table 3.3: Methods of VIA.	82
Table 3.4: Refraction and curvature coefficient as a function of elevation.....	106
Table 3.5: Refraction and curvature coefficient as a function of temperature	106
Table 4.1: LSIS database information related to urban landscape elements and their management.	116
Table 5.1: Factors to take into account to produce an accurate FVI.	136
Table 5.2: RGB limits of the eight colour groups accepted by the Bitmap Colour Counter.....	151
Table 5.3: Factors to consider when producing an image from a 3D CG modelling application.	154
Table 5.4: Percentage view results for figure 5.22.	156
Table 5.5: Percentage view change between before (poor visibility) and after (good visibility) scenarios.	159
Table 5.6: Percentage view change of various features.....	164
Table 5.7: Percentage view change of various viewpoint features.....	171
Table 5.8: Percentage view of tree belt and development every 3 years from initial planting.....	172
Table 6.1: Application of colour to features within the before and after models.....	193
Table 6.2: Percentage view of various features within the 3D model from the viewing platform.	194
Table 6.3: Percentage view of vegetation and proposed university hospital from critical viewpoints.	207
Table 6.4: Results of the percentage view analysis for the tower block (windows are ordered starting at the top left window, working across and then down).	208
Table 6.5: Percentage view of vegetation and psychiatric hospital from the critical viewpoints.	218
Table 6.6: Results of the percentage view analysis for the tower block (windows are ordered starting at the top left window, working across and then down).	220
Table 6.7: Application of colour to features within the three models.....	243
Table 6.8: Percentage view change of various features as viewed from critical viewpoint one.	245
Table 6.9: Percentage view change of various features as viewed from critical viewpoint two.	246
Table 6.10: Percentage view change of various features as viewed from critical viewpoint three.	247
Table 6.11: Percentage view change of various features as viewed from critical viewpoint four.	248
Table 6.12: Percentage view change from the road through Tiln South during quarrying.	250
Table 6.13: Percentage view change from the road through Tiln South post-development.	251
Table 6.14: Percentage view change of various features as viewed in winter.	254
Table 6.15: Difference in percentage view results between VR and 3D Studio MAX models.....	261

List of Graphs

Graph 6.1: Percentage view change of various features as viewed from critical viewpoint one.	245
Graph 6.2: Percentage view change of various features as viewed from critical viewpoint two.	246
Graph 6.3: Percentage view change of various features as viewed from critical viewpoint three.	247
Graph 6.4: Percentage view change of various features as viewed from critical viewpoint four.	248
Graph 6.5: Percentage view change from the road through Tiln South during quarrying.....	250
Graph 6.6: Percentage view change from the road through Tiln South post-development.....	251
Graph 6.7: Percentage view change of various features as viewed in winter from critical viewpoint one.	255
Graph 6.8: Percentage view change of various features as viewed in winter from critical viewpoint two.	255
Graph 6.9: Percentage view change of various features as viewed in winter from critical viewpoint three.	256
Graph 6.10: Percentage view change of various features as viewed in winter from critical viewpoint four.	256

1 Introduction

1.1 Introduction To Thesis

The field of Computer Graphics (CG) has been widely used for many different applications since its conception in the early 1960s, ranging from engineering and graphic design, to data visualisation and entertainment. The growing popularity of CG is due to a number of factors, including editability, repeatability, speed, accuracy, consistency and the ability to visualise complex data without difficulty in both two dimensions (2D) and three dimensions (3D). It is of no surprise, therefore, that CG have also been used for the assessment of potential impacts that may arise from proposed developments, such as air and water pollution, ground contamination and visual impact.

Assessing the change in visual appearance of the landscape is often known as Visual Impact Assessment (VIA). Changes in the visual character of the landscape have an immediate visible effect and can provoke strong feelings from the public, and in many cases the visual impact may become a key issue capable of influencing the Environmental Impact Assessment (EIA) decision making process (IEATLI, 1995).

There are three types of issues that VIA addresses; spatial, quantitative and qualitative (Fels, 1992). Spatial issues determine where the development is visible from. One technique for determining spatial visual impact is a Field of Visual Influence (FVI). Quantitative issues are concerned with how much of the development can be seen, how much area is affected and to what degree. Quantitative methods used to assess visual impact include solid angle calculations and percentage view analysis. Qualitative issues involve the visual character of the development and its compatibility with its surroundings. Examples include computer generated animations, perspective views and descriptive statements

It is currently recognised that VIA, unlike many other aspects of EIA, is a predominantly qualitative assessment since it is concerned with the human appreciation of the landscape (Wherrett, 2002). Furthermore, with few techniques available to quantitatively assess visual impact, the VIA process has become a primarily subjective procedure.

There are numerous VIA techniques and CG are presently being used to create photomontages, rendered images and animations, Virtual Reality (VR) simulations and FVIs. For proposed developments, there are very few quantitative CG techniques for the evaluation of visibility, and these existing methods can be highly inaccurate and time consuming (Cox and Schofield, 2002).

FVIs are the most common form of spatial techniques, however, they are also one of the most difficult techniques to produce accurately, using either CG or manual methods. The time taken to produce FVIs is also an important issue, especially when changes to a design require new FVIs to be produced.

A potentially important aspect of VIA is the ability to visualise change over time. Such examples include the change in vegetative foliage through the seasons and vegetative growth through the years. These changes have an important effect on the potential visual impact of a development, and must therefore be catered for within VIAs. Another potential consideration to take into account when producing a VIA, is the effect of Earth curvature and atmospheric refraction, which has the effect of lowering the line of sight of a development.

New and enhanced techniques for the assessment of visual impact are required that reduce the amount of subjectivity associated with VIAs. This thesis details the development of such techniques using CG and VR technology, which solve many of the problems associated with current VIA techniques.

1.2 Aims of the Research

The aims and objectives of the research detailed in this thesis are to improve upon and develop new techniques, using CG and VR technology, that could be used for the assessment of potential visual impacts arising from proposed developments. In particular, the research aims to:

- ?? improve the way FVIs are developed,
- ?? develop a technique to quantitatively assess the amount of view taken up by a proposed development,
- ?? develop a VR simulation which incorporates spatial, qualitative and quantitative VIA techniques,
- ?? allow the effects of Earth curvature and atmospheric refraction to be incorporated into the new and improved techniques,
- ?? investigate the effects of seasonal variation and growth of vegetation on visual impact, and develop a method to incorporate these effects into the new and improved techniques.

1.3 Overview of Thesis

Chapter 1 Introduction

An introduction to the research, presentation of the research aims and structure of this thesis is provided by this chapter.

Chapter 2 Computer Graphics and Virtual Reality

This chapter presents a literature review of the field of CG and VR covering definitions, the history of CG and VR, general application areas, types of software available and the theory behind the techniques. The topics discussed in this chapter are not intended to contain an exhaustive theoretical analysis of CG and VR, but instead detail aspects relevant to the work in this thesis.

Chapter 3 Assessing Environmental and Visual Impact

This chapter provides some background information on the EIA process and what it aims to achieve, its legislation in the UK and a brief description of the

current EIA process. The chapter will also explore VIA, a subset of EIA, in more detail including current and earlier techniques used to produce VIAs.

Chapter 4 Current Use of Computer Graphics and Virtual Reality for Visual Impact Assessment

A selection of academic and commercial case studies which apply some of the VIA techniques described in chapter 3 are shown in this chapter. The chosen case studies are not intended to be all encompassing, but instead have been chosen since they are representative of the current state of the use of CG and VR for VIA and combine to produce a broad range of different solutions to many of the problems commonly encountered with current VIA techniques.

Chapter 5 Development of New Techniques

This chapter describes the development of new and enhanced CG based techniques for VIA, namely FVIs and percentage view changes, and describes techniques which can be used in VIAs that consider earth curvature and atmospheric refraction and the effects of seasonal variation on vegetation. The use of VR to integrate existing VIA techniques and the novel CG techniques which have been developed is also discussed.

Chapter 6 Case Studies

A number of real world case studies which use and apply the new and enhanced VIA techniques that have been developed to assess visual impact are presented in this chapter. The chapter also gives a critical appraisal of the results gained from these techniques.

Chapter 7 Conclusions and Recommendations

Conclusions of the research detailed in this thesis. Further research that has been recommended by the author has also been expressed in this chapter.

Chapter 8 References

2 Computer Graphics and Virtual Reality

2.1 Introduction to Computer Graphics

2.1.1 Definition

CG has been defined in many ways and About, Inc. (2002) give a reasonable general definition when they define CG as:

“Graphics implemented through the use of computers, as well as the branch of science and technology concerned with methods and techniques for converting data to or from visual presentation using computers.”

CG involve the creation, manipulation, analysis and interaction with pictorial representations of objects and data using computers and can take form in either 2D or 3D. Pictures and graphs are examples of 2D graphics, while 3D graphics incorporate depth which allows models to be built which can be rotated, shaded, and manipulated to produce complex animation, such as those produced for television and motion pictures, for example “Toy Story” produced by Pixar in 1995 (Pixar, 2002). VR is a specific field of CG and will be discussed later in this chapter.

2.1.2 Development of Computer Graphics

William Fetter coined the term “computer graphics” in 1960 in order to describe new design methods he was pursuing at Boeing. He created a series of widely reproduced images on a plotter exploring cockpit design using a 3D model of a human body. However, the first truly interactive graphics system called “Sketchpad” was pioneered at MIT by Ivan Sutherland for his 1963 Ph.D. thesis. Interaction with Sketchpad was with the use of a Cathode Ray Tube (CRT) monitor, light pen and function-key panel. Before this, user input was generally in the form of keypunch and output via plotters and printers (Foley *et al.*, 1994 and Van Dam, 2002).

During the 1960s the first Computer Aided Design and Manufacturing (CADAM) systems were developed. Kerlow (2000) states:

“The goal of these early CADAM systems was to make the design process more effective by offering users sophisticated design functions and to improve the organisation of the manufacturing process by linking the numerical data that represents an image with other types of information, such as inventory and engineering analysis.”

Until the early 1980s, CG was a small, specialised field, largely because the hardware was expensive and graphics-based application programs were few. Kerlow (2000) states:

“The use of computer graphic systems during the 1960s was clearly restricted by the high cost and limitations of the hardware involved... Most programs were executed in the batch mode, and very few had any interactive features at all. Users had to input their data almost exclusively through the keyboard; other types of input peripherals that encouraged more artistic freedom were just not available. A few computer systems had graphics screens, but most had monochrome alphanumeric CRT screens or even just teletype or dot matrix printers.”

Many of the basic rendering techniques in use today were developed in the 1970s, and with the price of computer hardware dropping in the late 1970s and early 1980s, Personal Computers (PCs), such as the Apple Macintosh and the IBM PC, popularised the use of interactive CG (Foley *et al.*, 1994).

Pointing and clicking on a graphical interface via devices such as mice and trackballs have replaced the need for typing monotonous commands into earlier computers. Today, almost all interactive application programs use some form of CG as graphical user interfaces in one way or another, from word processors and spreadsheets to games and Computer Aided Design (CAD).

2.1.3 Applications of Computer Graphics

CG are used in many diverse areas such as industry, business, government, education and entertainment, and the number of applications in which CG are used is extensive and rapidly growing. Below are descriptions of a few of the applications of CG.

2.1.3.1 Engineering, Design and Visualisation

A major use of CG is in the engineering field to design and visualise objects. CAD is often used for this purpose as it can produce precise drawings of components and assemblies. Foley *et al.* (1994) state:

“In computer-aided design (CAD), users employ interactive graphics to design components and systems of mechanical, electrical, electromechanical, and electronic devices, including structures such as buildings, automobile bodies, airplane and ship hulls, very large-scale integrated (VLSI) chips, and telephone and computer networks.”

As well as CAD packages, 3D CG software packages are also available that can create photo-realistic models using shading algorithms, textures, lighting and shadows. Models can also be animated, for example architects use CG techniques to produce walkthroughs of their designs to help clients visualise what the designs will look like. CG can also play an important role in environmental engineering, for example, to visualise proposed developments, air pollution flow and landfill leachate flow.

The fields of science and mathematics uses CG to visualise mathematical models as Foley *et al.* (1994) state:

“We can use them (CG) to study abstract mathematical entities as well as mathematical models of such phenomena as fluid flow, relativity, nuclear and chemical reactions, physiological system and organ function, and deformation of mechanical structures under various kinds of loads.”

The advantage of using CG for engineering, design and visualisation is that designs can be shown in both 2D and 3D and since they can be interactive, designs can be changed with ease. Figure 2.1 shows a screenshot of a typical CAD interface with a 3D model being shown in both plan and perspective views.

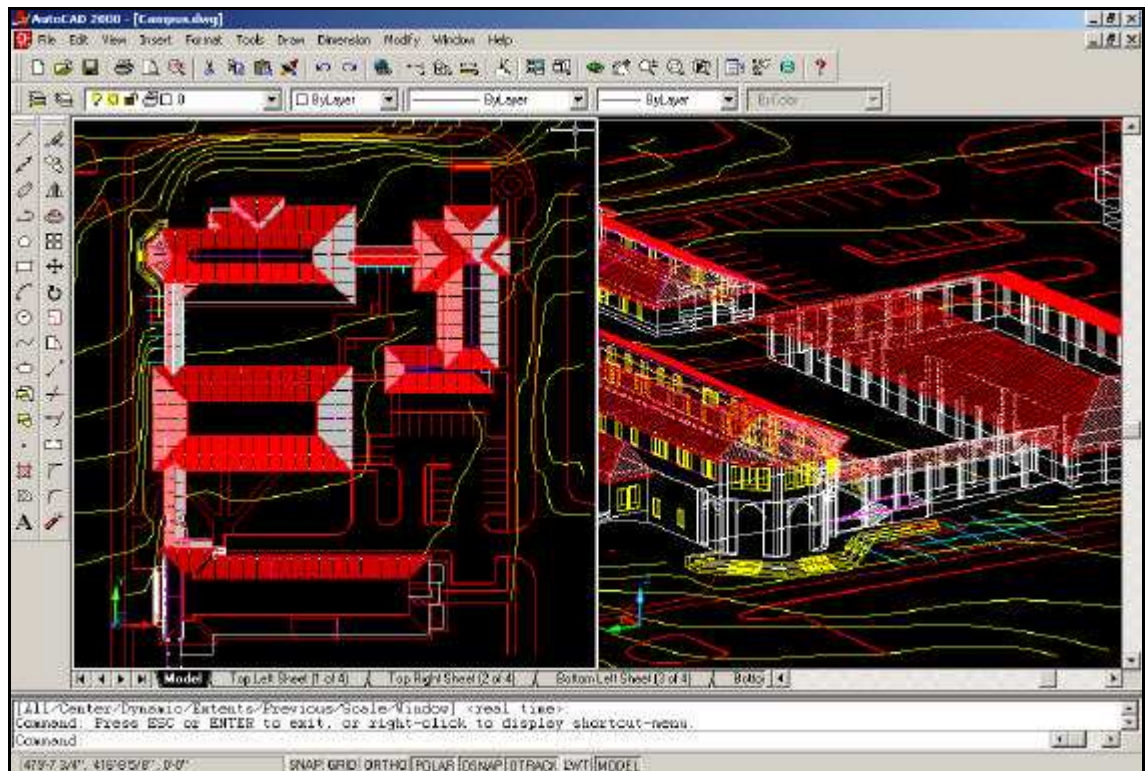


Figure 2.1: Typical CAD software package interface¹.

2.1.3.2 Accident Reconstruction

Based on accident survey data, CG can be used to accurately recreate accidents for presentations in trials, industrial hearings, public enquiries or for settlements. Schofield (2000) states:

“The ability to represent a range of crime or accident scenarios and view those scenarios from any angle enables investigators, and jury members, to better understand the underlying causes of an accident.”

¹ Screenshot taken by the author (November 2002) of a demonstration model packaged with AutoCAD (Autodesk, 2002c).

The AIMS Research Unit at the University of Nottingham use CG technology to reconstruct both traffic and industrial accidents in the UK and abroad. Using accident survey data, the environment can be accurately and realistically recreated in detail using 3D CG software.



Figure 2.2: Perspective view of an accident reconstruction².

Using road accident reconstruction as an example, animations can be produced from various locations such as the driver or witness view, or from overhead or perspective views (figure 2.2). Various scenarios, such as driving speeds and vehicle locations, can also be shown according to varying witness statements.

² 3D model by the author (with Gilbert, T and Schofield, D.) for AIMS Solutions (June 2002).

2.1.3.3 Education and Training

CG can be useful as an educational aid in situations where it is difficult to replicate real world scenarios such as hazardous, inaccessible or expensive environments. Examples include flight and driving simulators, which, in the real world, would involve expensive equipment and the potential for human injury.

The AIMS Research Unit have for many years produced training videos and simulations using CG for a range of industrial applications. Dangerous situations can be randomly created and the trainee must spot hazards and avoid potential accidents before they occur. Figure 2.3 shows an image from Safe Driver, a safety training application, developed by AIMS Solutions Ltd., which shows users the potential hazards within numerous working environments.



Figure 2.3: Rendered image from Safe Driver, a CG safety training application³.

³ Rendered image by AIMS Solutions (2002).

Developing training videos and simulations using CG can be very time consuming, with potentially large, complex environments having to be modelled with great accuracy and detail. However, the cost of producing CG based training videos and simulations can be comparatively low when compared with the costs incurred by the difficulties of training with expensive, hazardous equipment in problematic environments and the cost involved with real filming.

2.1.3.4 Entertainment

The entertainment industry has had a large effect on the development of software and hardware for CG. Newly developed computer games and films are constantly pushing the boundaries of computer hardware and software and in response manufacturers have created faster and more powerful graphics hardware and software. Currently, CG hardware is powerful enough so that many games can look exceptionally realistic while still maintaining a high frame rate at high resolutions.



Figure 2.4: Image from Pixar's Toy Story⁴.

⁴ Image by Pixar (2002).

Motion picture films have been using CG technology for visual effects for some time, but in 1995 Pixar's "Toy Story" (Pixar, 2002) became the first feature animated film to be entirely created with 3D computer animation techniques (figure 2.4). Since then, many motion picture and television companies have produce entire films and television series using the technology.

2.1.3.5 Medicine

Medicine is increasingly using CG technology in order to diagnose problems with patients and as an aid to surgery as Foley *et al.* (1994) explain:

"...surgeons use graphics as an aid to guiding instruments and to determine precisely where diseased tissue should be removed."

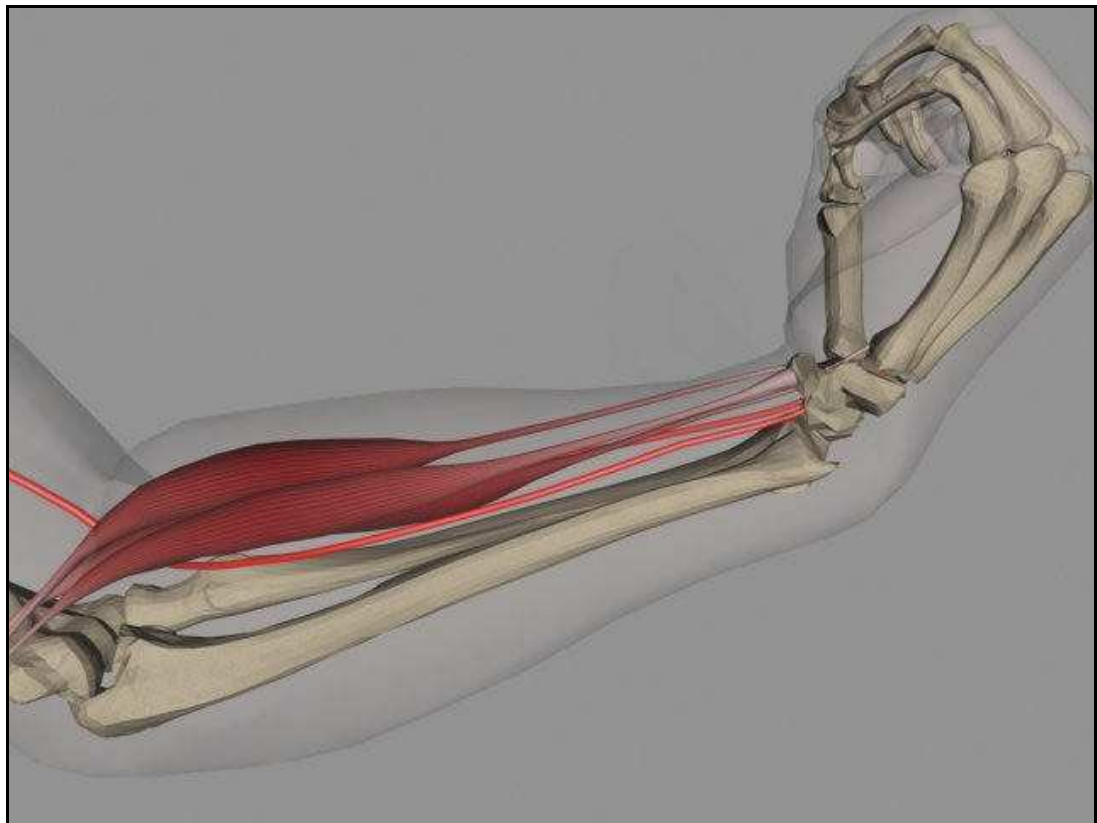


Figure 2.5: A 3D model of a human lower arm⁵.

⁵ Image from a 3D CG model by Mr. J. March (2003).

Figure 2.5, produced as part of a Ph.D. at the University of Nottingham, shows an image of a man's lower arm that was used to investigate the circumstances of his death. Although this model has been used for reconstruction purposes, 3D models can serve a variety of purposes such as a guide to the human anatomy, surgical procedures, bio-mechanics and Magnetic Resonance Imaging (MRI), which can, for example, produce 3D representations of the human brain which can be interactively manipulated to reveal detailed information about its condition (Foley *et al.*, 1994).

2.1.3.6 Art

Both 2D and 3D CG software packages are used by graphic artists to produce images for a number of applications including, magazine illustrations, logos, adverts and web page designs. Figure 2.6 shows a company logo produced using a 2D CG software package for AIMS Solutions Limited.



Figure 2.6: A typical logo created using a CG software package⁶.

Before the widespread use of computers, images were created by hand and required a skilled artist and a large amount of time, and mistakes could not easily be rectified. However, with the use of CG mistakes can be undone at the press of a button and images can be duplicated, modified and resized very easily.

2.1.3.7 Data Visualisation

CG can be used to present data such as mathematical, physical and economic functions in a

⁶ Logo by AIMS Solutions Ltd. (2002).

graphical and informative method. Presentation forms include histograms, line graphs, pie charts and scatter graphs. Foley *et al.* (1994) state:

“...graphs are used to present meaningfully and concisely the trends and patterns gleaned from data, so as to clarify complex phenomena and to facilitate informed decision making.”

Data can also be visualised in 3D, with example applications including air flow, heat dissipation and noise levels. Figure 2.7 shows an image of a 3D CG model, developed during an undergraduate project at the University of Nottingham, which illustrates the distribution of noise which is produced from traffic passing on nearby roads. A cloud of spheres illustrates the magnitude of noise through their colour and size. Red spheres indicate a high noise level, while blue spheres indicate a low noise level.

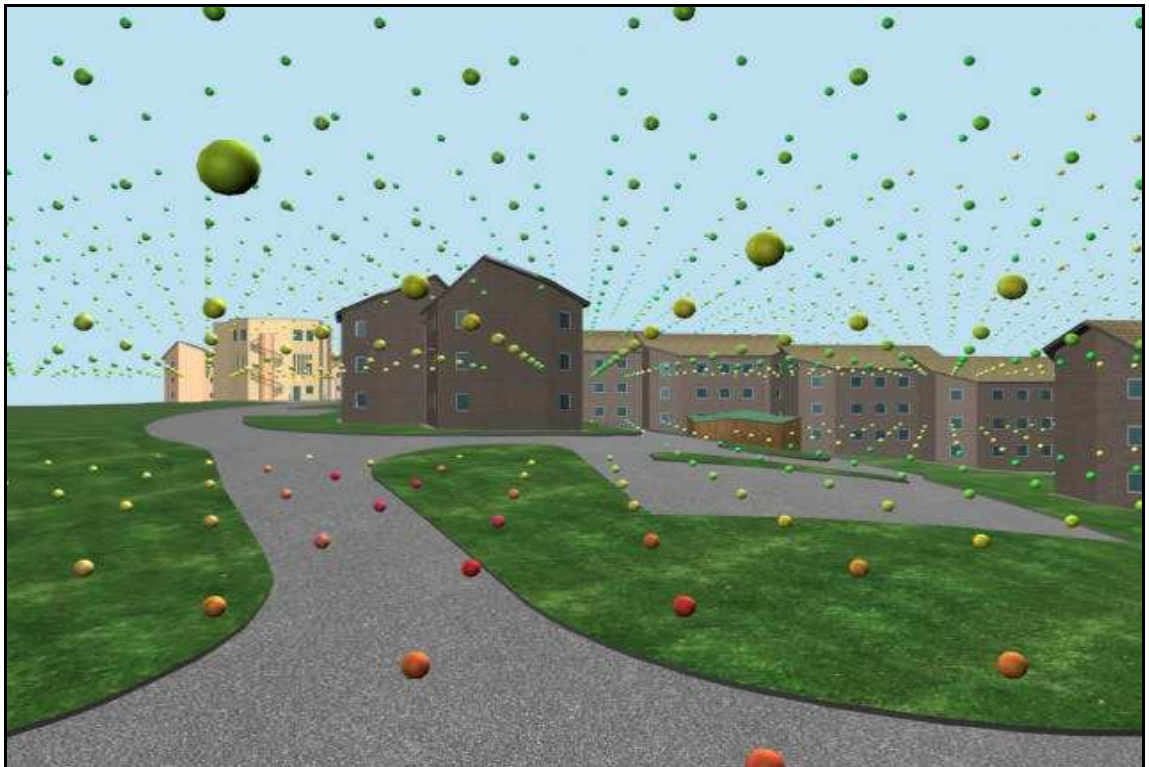


Figure 2.7: A cloud of particles representing noise levels through their colour and size⁷.

⁷ Image and 3D model produced by Ward (2002).

2.1.4 Software

There are three main types of CG software; 2D image processing, CAD, and 3D modelling and animation. These are briefly discussed below with some examples of commercially available software. A Geographical Information System (GIS) can be made up of a combination of these software types and is also discussed below. Software that has been used in this thesis is discussed in more detail in appendix 1.

2.1.4.1 Image Editing

Image editing software applications are used to create and edit images. Example uses for such software include creating logos, creating textures for use in 3D modelling packages, scanning and retouching photographs, and creating artwork.

Example packages include Photoshop (Adobe Systems Inc., 2003), Paint Shop Pro (Jasc Software, 2002), CorelDRAW (Corel Corporation, 2002) and Mattis and Kimball's GIMP (GIMP, 2002), with current prices of the above software ranging from hundreds of pounds to free.

2.1.4.2 Computer Aided Design

Approximately 25 years ago, almost every technical drawing produced was done by hand. Small changes to the design meant erasing and redrawing, while major changes often meant having to recreate the drawing. Often a change to one drawing could affect other drawings which meant that someone had to track the changes to series of other drawings.

The introduction of CAD changed all this and revolutionised the way designs were produced, having a direct effect on accuracy and productivity. The advantages of CAD are speed, accuracy, consistency and the flexibility to make changes or revisions without having to redraw

the project and it is a great asset with repetitive work.

CAD has been around since the early 1960's, its use facilitates the design of objects through computers. Early CAD software packages only worked in wire frame (simple line models) on a 2D plane, nowadays they can operate in 3D using various shading techniques to produce realistic rendered images.

There are many CAD packages on the market and below is a list of just a few with current prices ranging from £100 to £4000:

- ?? TurboCAD (IMSI, 2002).
- ?? AutoCAD (Autodesk, Inc., 2002c).
- ?? ArchiCAD (Graphisoft, 2002).
- ?? MicroStation (Bentley Systems Inc., 2002).

2.1.4.3 3D Modelling and Animation

3D modelling and animation applications differ to CAD in that they have the ability to create realistic environments by means of complex animations, lighting and shadows, detailed surface texturing, reflective surfaces, environmental effects such as fog and rain and many other functions. Unlike CAD, these type of CG software are not generally used for design purposes since they usually do not have the ability to plot design drawings or hold design data (such as pricing and material properties for example).

There are many software packages for 3D modelling and animation ranging from professional applications used by motion picture film companies, which are priced in the thousands, to amateur applications for the general public, which are available for under a hundred pounds.

Discreet's "3D Studio MAX" (Autodesk, Inc., 2002b) is a popular package for 3D modelling, animation and rendering which is used by many computer game designers and film producers

and currently retails at approximately £2400. The computer game “Return to Castle Wolfenstein”, by Gray Matter Interactive Studios (2001), and the recent film “Tomb Raider” both used 3D Studio MAX to build 3D environments (Autodesk, Inc., 2002). AIMS Research, at the University of Nottingham, use this modelling software as one of the main tools in the production of accident reconstructions, safety training videos, and environmental visualisations. Figure 2.8 shows a screenshot of the 3D Studio MAX interface.

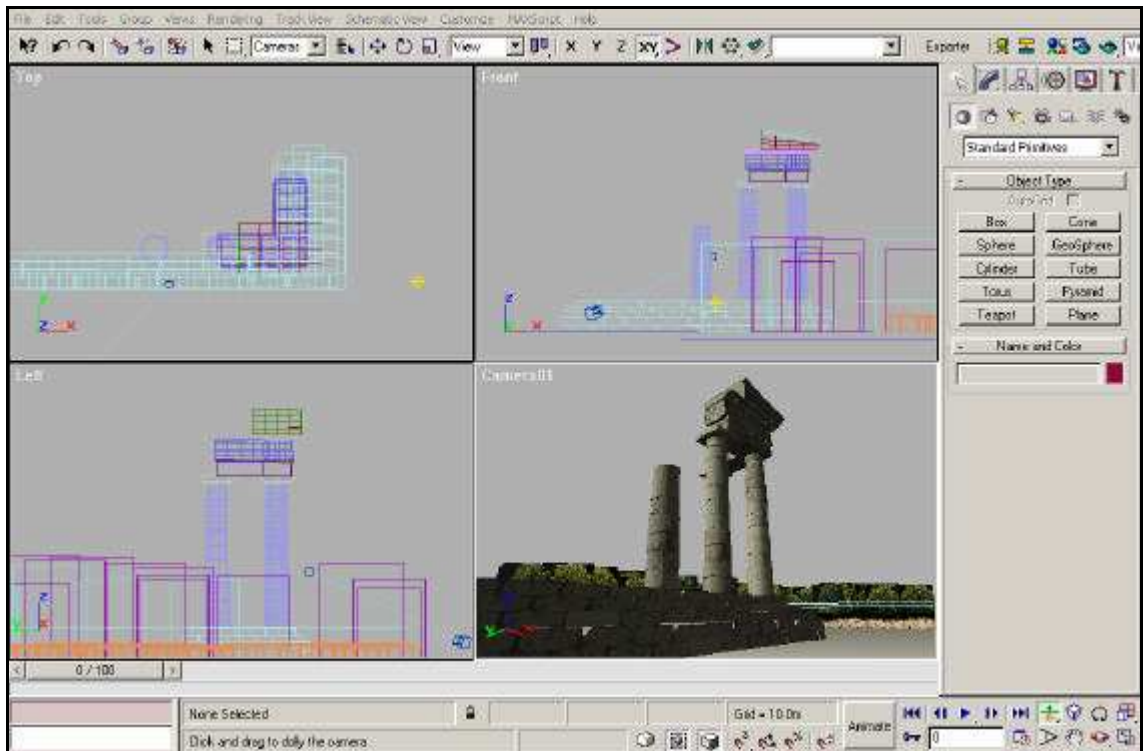


Figure 2.8: Screenshot of 3D Studio MAX⁸.

Maya (Alias/Wavefront, 2002) is another popular 3D modelling and animation package used in computer game development and film production and currently retails at approximately £1400. Other packages include Bryce (Corel Corporation, 2002), Vue D’Esprit (E-on Software, 2002) and Lightwave (NewTek, 2002), with current prices of these ranging from £140 to £1100. Appleton *et al.* (2002) have assessed a number of different visualisation software packages that all have the ability to use a GIS database (described below) as source data for 3D CG modelling.

⁸ Screenshot and 3D model by the author (February 2002).

2.1.4.4 Geographical Information Systems

A GIS is a computer system capable of assembling, storing, manipulating and displaying geographically referenced data. A GIS can provide powerful tools whereby layers of data on a variety of topics can be collated, sieved, selected or superimposed (LITIEMA, 2002 and US Geological Survey, 2002). LITIEMA (2002) describe the types of data a GIS may often include:

“...baseline data may include vegetation cover and habitat distribution, topography, soils, archaeological sites, population and settlement data, drainage catchments, transportation, land use, cultural features and landscape character areas.”

In a GIS, data is not only represented in pictorial form, as in conventional paper maps, but as information or data which can be converted into charts and graphs for example. A GIS can also incorporate 3D modelling to create terrain models and basic structures and vegetation blocks which can then be used to help visualise the environment and produce simple fly-throughs or visual impact analysis for example.

Since GISs are designed as a generic system for handling many kinds of spatial data, they have a wide range of applications in both urban and rural environments. Typical fields of work which use a GIS include agriculture, forestry, wildlife, EIA, archaeology, geology and urban applications such as utilities, management of storm water, allocation of emergency services, crime analysis and disease outbreak (Itami and Raulings, 1993).

2.2 Theory of Computer Graphics

This section introduces some of the basic principles of CG. The topics discussed below are not intended to contain an exhaustive theoretical analysis of CG but instead detail aspects relevant to the work in this thesis.

2.2.1 Bitmap Images

There are two kinds of CG images, “raster”, which are composed of pixels, and “vector”, which are composed of line paths. This section discusses raster graphics, commonly referred to as bitmap images.

A bitmap image consists of a matrix of individual dots (or pixels) that each have their own colour value which are described using bits, the smallest possible units of information for a computer. Figure 2.9 shows an example bitmap image with a section of it enlarged that shows the individual pixels that make up the image.

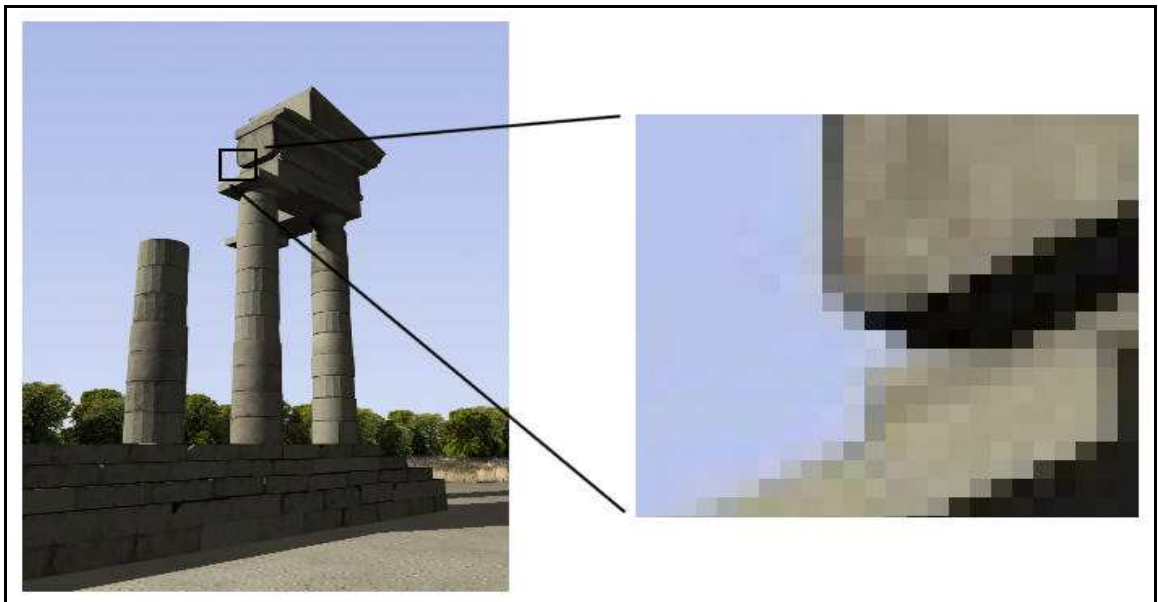


Figure 2.9: Example of a bitmap image illustrating its individual pixels⁹.

Bitmap data can be saved in a wide variety of file formats, some of which use compression techniques (bitmap images can take up a large amount of physical memory and hence compression is often used to reduce files sizes). There are two types of compression, lossless and lossy. Lossless compression retains all of the original image data and reduces the file size by storing patterns of pixels in the image, while lossy compression eliminates data in order to reduce the file size. Banta Corporation (2001) describe lossless and lossy compression

⁹ Rendered images from a 3D model created by the author (September 2002).

techniques as:

*“Lossless compression refers to data compression techniques in which no data is lost...
...The best use of lossless compression is to compress text files as opposed to pictures
files. Typically, a text file can be compressed 50% with a lossless compression, while
pictures 15% or less. Lossy is a compression that became popular with the introduction
of JPEG in 1992.....JPEG is a lossy compression meaning that data is thrown away. Its
compression technique is a transform coding method based on the discrete cosine
transform (DCT). DCT works by dividing an image into smaller 8 x 8 blocks and placing
them in the file one after the other and then applying the transform to each of these image
blocks. You have a quality and compression option with JPEG. The higher the
compression, the more frequently information is discarded. Lossy is fast because it works
consecutively on small image blocks, but has some important drawbacks. The most
apparent is the so-called blocking effect, when the edges of the small image blocks are
easily seen in a decompressed image.”*

Figure 2.10 shows an example of the difference in image quality due to lossy compression. The image on the left shows a portion of figure 2.9 saved as a JPEG file using a compression setting of fourteen percent, while the image on the right was saved as a BMP file without compression. File sizes of the full images were 7 kilobytes and 901 kilobytes respectively. Table 2.1 lists a few of the common image file types with their associated advantages and disadvantages.

One of the biggest disadvantages of bitmap images over vector images is the jagged edges between different parts of an image. Vector images do not have this problem since they use mathematical relationships between points and the paths connecting them to describe the image, not pixels. The jagged edges of bitmap images can be overcome with the use of anti-aliasing, a technique which smooths the edges by blending the pixel colours along those edges, as shown in figure 2.11. The use of higher resolutions can also give a bitmap image a smoother appearance.

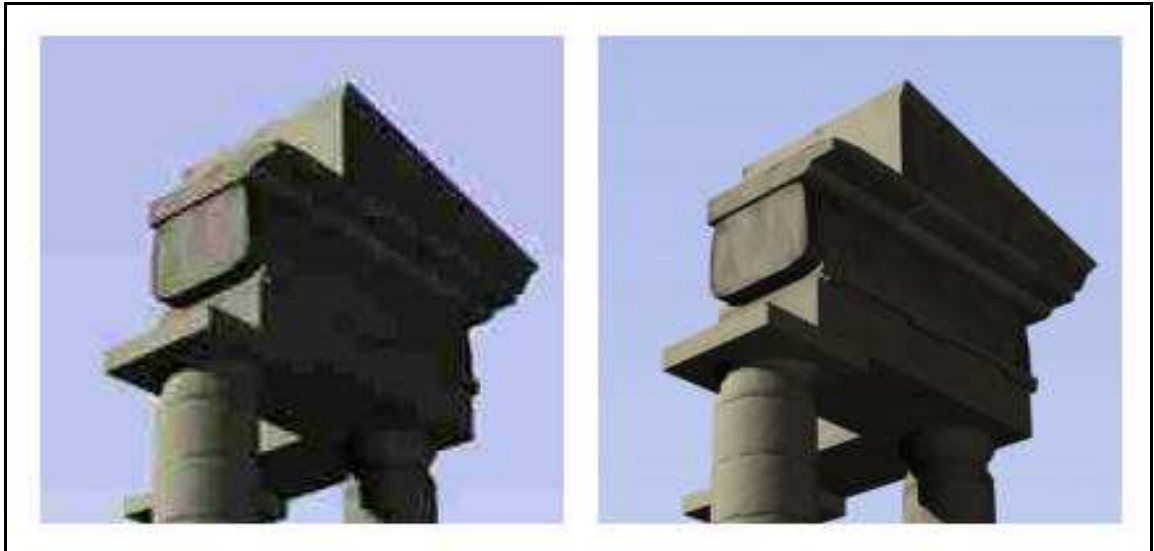


Figure 2.10: Compressed versus uncompressed (left and right respectively)¹⁰.

File Type	Advantages	Disadvantages
BMP (Bitmap)	Lossless compression.	Large file sizes, does not support transparency or layers.
JPEG (Joint Photographics Experts Group)	Degree of compression can be set from 1-99.	Lossy compression, does not support transparency or layers.
TIFF (Tagged Image File Format)	Various lossless compression types, one alpha channel.	Does not support layers.
TGA (Truevision Targa)	Lossless compression, one alpha channel.	Does not support transparency or layers.
GIF (Graphics Interchange Format)	Lossless compression, transparency, interlacing and storage of multiple images.	Can only use 256 different colours in a single image, does not support layers or alpha channel.
PNG (Portable Network Graphics)	Lossless compression, one alpha channel, alpha transparency.	Does not support layers.
ECW (Enhanced Compressed Wavelet)	Efficient compression for large files.	Lossy, not supported by many image editing applications.

Table 2.1: Common file types and some of their advantages and disadvantages.

¹⁰ Rendered images from a 3D model created by the author (September 2002).



Figure 2.11: The effect of anti-aliasing (applied to image on right)¹¹.

2.2.2 The RGB Colour Model

Colour models are systems for creating a whole range of colours from a small set of primary colours. There are two types of colour model; additive and subtractive. Additive colours are created by mixing spectral light in varying combinations, a common use of this method is in computer monitors. Subtractive colours are based on light being absorbed and reflected by paint and ink and this method is often used for print.

There are a number of colour models used in CG, but the two most common are the RGB model, which uses red, green and blue light and is additive, and the CMYK model, which uses cyan, magenta, yellow and black pigments and is subtractive. Figure 2.12 shows these two colour models. The work described in this thesis has been concerned with the additive RGB colour model since most of the output will be displayed on a monitor.

The RGB model has three primary colours; red, green and blue, which are created by emitting light. These primary colours can be combined in various proportions to produce many other colours. Generally, modern computers display RGB using 24-bit colour which means that there

¹¹ Rendered images from a 3D model by the author (Sep 2002).

are up to 256 variations for each of the three primary colours, giving a total of 16,777,2126 possible colours.

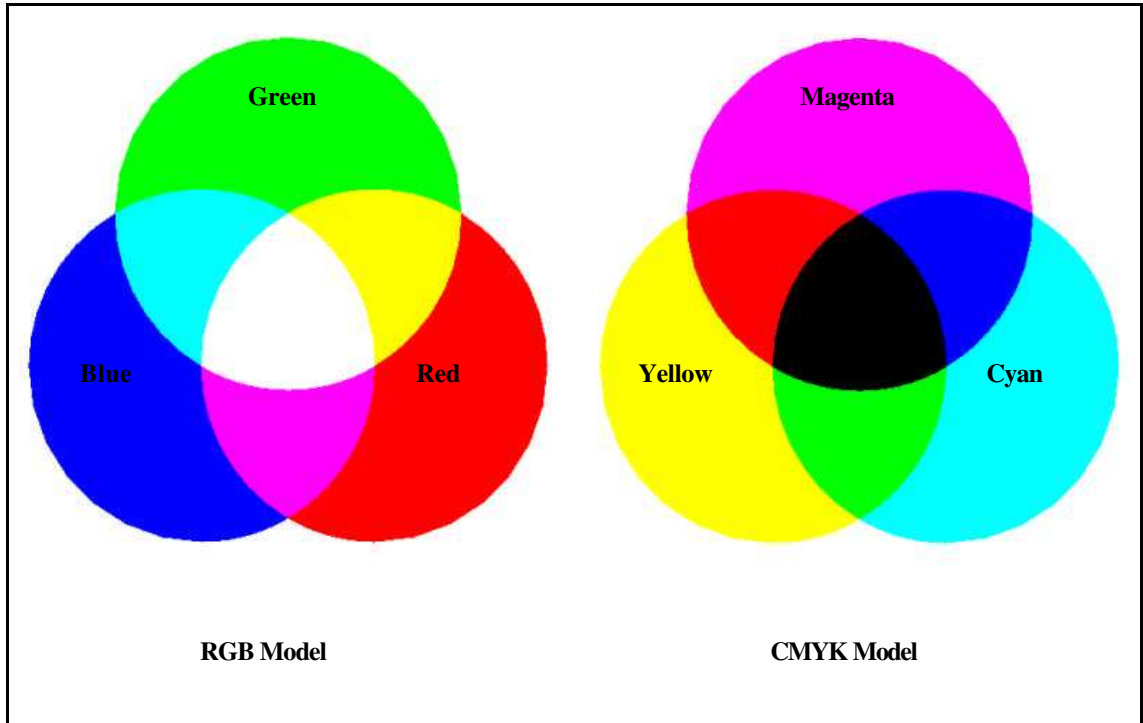


Figure 2.12: Additive RGB model and subtractive CMYK model¹².

Colour (pure)	RGB Settings		
	Red	Green	Blue
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Yellow	255	255	0
Azure	0	255	255
Violet	255	0	255
Black	0	0	0
White	255	255	255

Table 2.2: RGB settings for the standard white light colour spectrum.

¹² Image by the author (October 2002).

The primary colours are measured as a value from 0-255, with 0 being the least intensity and 255 the highest. The colours produced when these primary colours are mixed depend upon their relative strength. For example, pure red has a red value of 255, a green value of 0 and a blue value of 0. The absence of all of the three primary colours results in pure black, whilst the presence of all three, at full strength, results in pure white. Table 2.2 shows how a selection of colours are produced by the mixture of the three RGB primaries.

2.2.3 Basic 3D Modelling Concepts

Kerlow (2000) defines 3D modelling as:

“The spatial description and placement of imaginary three-dimensional objects, environments, and scenes with a computer system...”

This section explores the fundamental concepts of the modelling process including the basic building blocks used for the creation of objects and moving, rotating and resizing objects in 3D space.

2.2.3.1 Co-ordinate Systems

Within the field of 3D CG there are three perpendicular axes, which are conventionally labelled as the x, y and z axes (figure 2.13). The main point of reference in the 3D modelling space (or world) is called the world origin, and is the point in space where the three axes intersect. Distances from the origin to a point in space are referred to as x, y and z values. It is also possible to rotate about the three axes and these rotations are often referred to as pitch (rotation about the x axis), yaw (rotation about the y axis) and roll (rotation about the z axis). This type of co-ordinate system is known as the Cartesian co-ordinate system formalised by Rene Descartes in the eighteenth century (Watson, 2002).

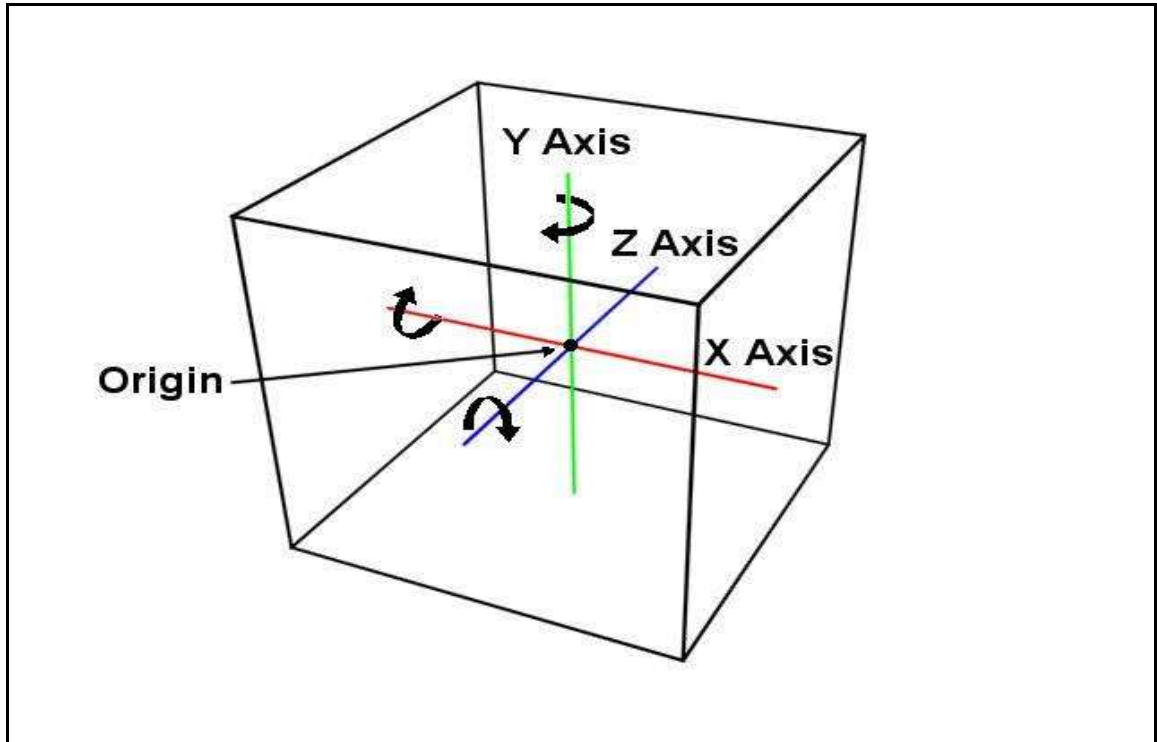


Figure 2.13: Co-ordinate system¹³.

In addition to this world co-ordinate system each object in the world may also have its own local co-ordinate system, which uses values relative to the origin of the object (usually placed in the centre of the object).

2.2.3.2 Points, Lines and Faces

Points, lines and faces (also known as vertices, splines and polygons) are among the basic elements that can be used to build 3D objects. A point can be easily defined by its XYZ values (values along x, y and z axes respectively), a line is defined by the XYZ values of its two endpoints and similarly, a face is defined by the XYZ values of the points that outline it (the points on a face must all be planar). Figure 2.14 shows an example face in 3D space.

Each face has a face normal, which is a vector that defines which way the face is pointing. Normals are used to define which side of a face should be rendered and they can be manually

¹³ Image by the author (October 2002).

flipped or unified to fix surface errors caused by modelling operations or by importing meshes (3D wireframe models) from other programs.

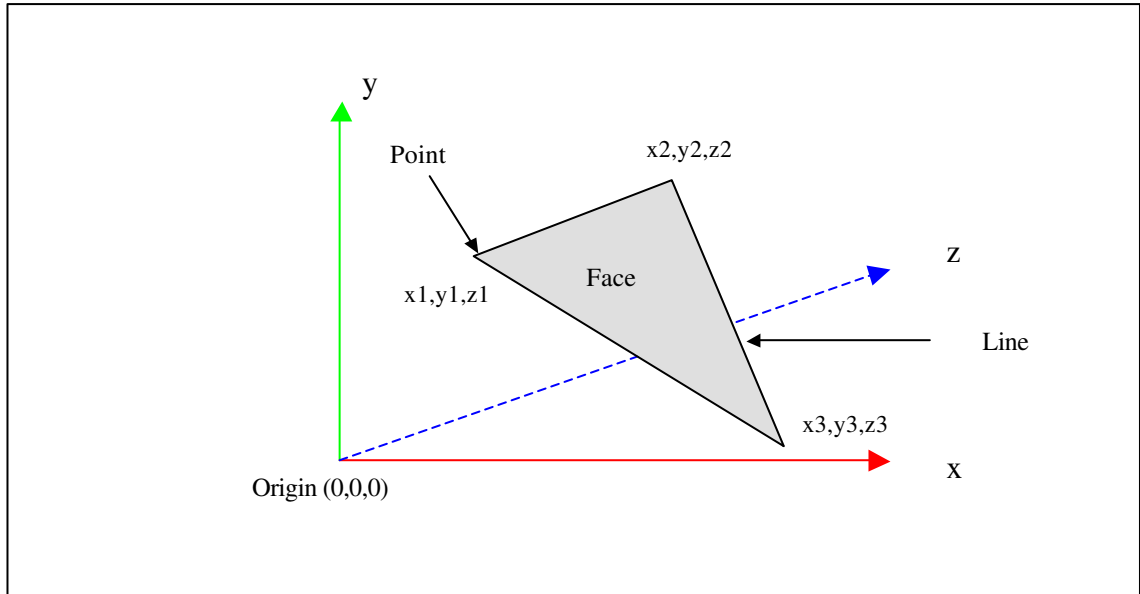


Figure 2.14: Example of a 3D triangulated face¹⁴.

A number of faces can be combined to produce a shape or model. Some complex models, such as a human skeleton, may require thousands of faces, while a simple box can be produced with just six (although some modelling packages count each side of a box as two triangular faces which creates a box with a total of twelve faces).

Objects can also be defined with curves instead of straight lines, this is known as a parametric representation. Curved lines include cardinal splines, b-splines, NURBS (Non-Uniform Rational B-Splines) and Bézier curves (Kerlow, 2000). 3D surfaces can be produced using these curved lines. Curved lines and surfaces are explained in more detail by Watt (2000).

2.2.3.3 Geometric Transformations

Geometric transformations are the functions often used for modifying the shape of objects, their

¹⁴ Image by the author (October 2002) after Schofield (2000).

size and proportions as well as their position in space. The most common transformations include translation, rotation and scaling.

Transformations can be applied to entire environments, single objects, or single primitives (points, lines and faces). When applying a transformation it is important to specify the axis or axes in which the transformation is to be applied and which origin, world or local, is to be used.

2.2.3.4 Digital Elevation and Terrain Models

A Digital Elevation Model (DEM) is a 3D digital representation of the height and shape topography of a surface. Usually DEMs are mainly used for modelling landscapes, so the surface usually relates to the Earth's surface but this is not always the case. DEMs can also be used to define other surfaces such as vegetation or building surfaces or a mixture of a number of surfaces. When overlaid with other data relating to features on the surface, such as an aerial photograph or slope data, it is known as a Digital Terrain Model (DTM) (Ordnance Survey, 2001a).

2.2.4 Lights, Cameras and Shading and Surface Characteristics

This section provides an overview of setting a scene using virtual lights and cameras and a brief description of the various shading and surface options available for 3D modelling.

2.2.4.1 Lighting and Shadows

Lights are used to provide illumination to objects in 3D environments and can be very important to the final appearance of a virtual scene. There are many types of light sources which each give different atmospheric effects, these include; ambient, infinite, point, spot, area and linear. Figure 2.15 demonstrates the difference between some of the commonly used light sources.

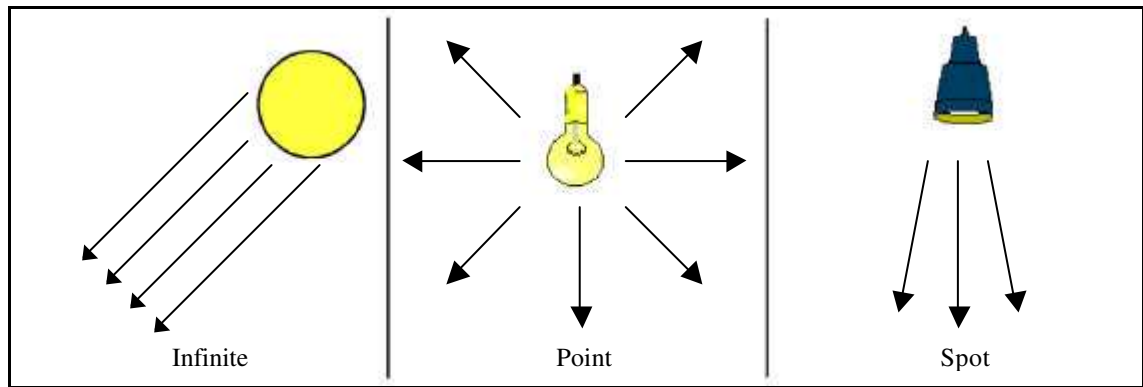


Figure 2.15: Examples of light sources¹⁵.

Ambient light is general background lighting which is distributed evenly throughout an entire scene and often determines a general level of illumination, or shade, of a scene. Since it is difficult to replicate light that is reflected off surfaces within a real environment due to the numerous time consuming interreflection calculations, ambient lights are used to represent this reflected light.

Infinite lights (also known as directional lights) use parallel light rays and have a direction which defines the direction in which the light radiates. The sun is an example of an infinite light source, and some 3D modelling packages allow the user to place sun light accurately by specifying the geographical location of the scene and the date and time.

A point light casts light evenly in all directions and is sometimes referred to as an omnidirectional (or omni) light. Point lights are the simplest of light sources and can be placed anywhere in a scene. A naked light bulb is an example of a point light.

A spot light is similar to a point light except the light is cast in a cone shape and is therefore directional. In virtual worlds, spot lights behave similarly to spot lights used in theatres for example, having both hotspots, falloff and umbras. A spot light's hotspot is defined as the brightest spot of the light cast in the centre and the umbra defines the edges of the cast light.

¹⁵ Images by the author (October 2002) after Schofield (2000).

Area and linear lights are less commonly used in 3D modelling packages. Area lights can either be in the form of multiple lights grouped together, or as a single large area of light, usually rectangular or circular in shape. Linear lights have length but no width and a real world example of something similar is the light emitted by fluorescent tubes (Kerlow, 2000).

Light sources can have any colour, specified using an additive colour model, usually the RGB model. The intensity and brightness of lights can also be modified (and sometimes animated) to suit the environment. In reality, some light sources decay with distance, and many 3D modelling packages have a decay function which allows the user to specify how the light attenuates over distance.

Shadows play an important part in making a 3D CG world realistic. They not only emphasise the direction of light, but anchor objects to the ground so they do not appear to be floating in space (figure 2.16). Shadows, in a virtual environment, may have a number of parameters that can be set to change their appearance, including the colour of the shadow, the softness of the shadow edge and the rendering method employed which results in different levels of accuracy.

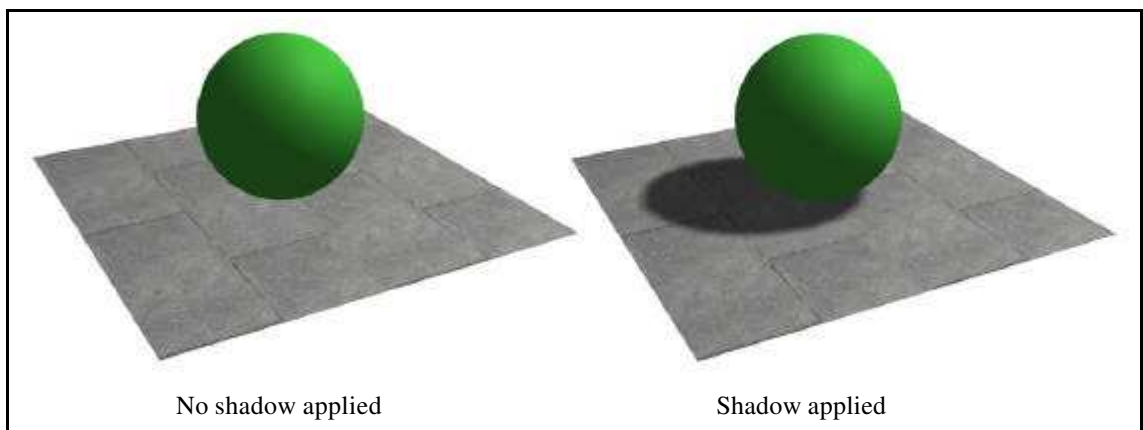


Figure 2.16: Anchoring effect of shadows¹⁶.

¹⁶ 3D models created by the author (October 2002).

2.2.4.2 Cameras

Kerlow (2000) describes the importance of cameras in a virtual environment:

“Cameras are a small but essential detail in the rendering process mostly because they define what we see in the shot, where we see it from, and how we see it. And while many of the steps in composing the shot have to do with arranging and defining the objects in front of the camera, defining and positioning the camera itself marks the beginning of the rendering process.”

What a virtual camera sees in 3D space is usually defined by the position and direction of the shot, the image aspect ratio and the type of lens. The relation between the width and the height of the image defines the aspect ratio and the standard varies between media formats. The default for 3D modelling packages is usually 4 to 3 which is also the aspect ratio for most computer monitors.

The type of lens used for cameras is very important. Kerlow (2000) describes the difference between lenses:

“In general, lenses with a short focal length offer a wide angle of view and increased depth of field, but objects appear distant to the camera. Inversely, lenses with a long focal length have narrow angles of view and depth of field.”

For normal shots a 50 or 55 mm lens is usually suggested as it does not distort the view, and hence gives an accurate representation of the scene. A human field of view is also represented well by this type of lens.

2.2.4.3 Surface Shading Techniques

There are many techniques for shading the surface of an object, but the three main techniques are faceted, smooth and specular shading (figure 2.17). Faceted shading assigns a single and

constant shading (colour) value to each visible polygon of an object according to the angle of its normal (direction of the face) in relation to the light source. The effect of faceted shading is that each polygon in the model is clearly distinguished from the rest.

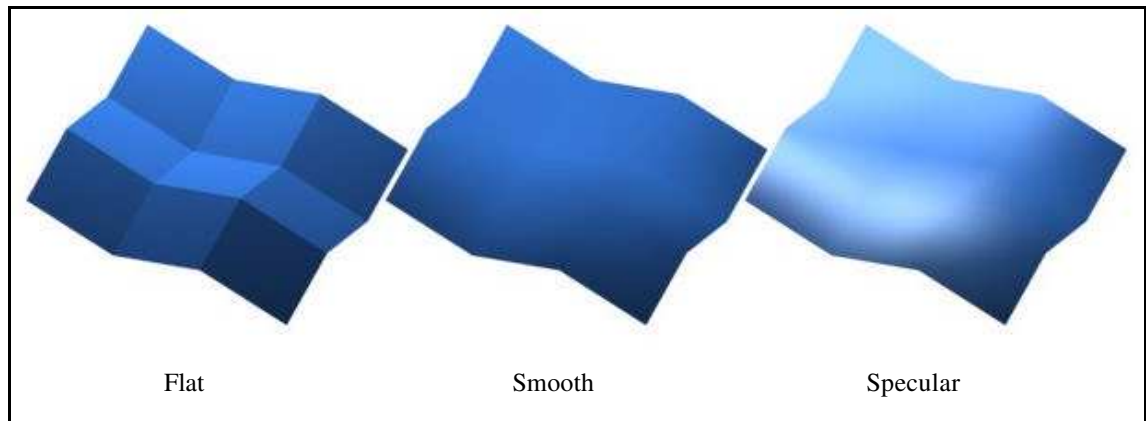


Figure 2.17: Different shading types¹⁷.

Smooth shading assigns a continuous shading value that blends throughout visible polygons, creating a smooth transition between those polygons. Gouraud shading is an example of a smooth shading model which is used by many 3D modelling packages. Specular shading creates surfaces with highlights and a smooth continuous shading across polygons. Phong and Blinn shading are popular examples of specular shading models (Kerlow, 2000). An additive colour model, such as RGB, can be used to give objects colour.

2.2.4.4 Image Mapping

Image mapping (or texture mapping) is used to give objects more detail and complexity. The method basically consists of taking 2D raster images (commonly referred to in this context as maps) and “mapping” them on to the surfaces of 3D objects. The 2D images do not necessarily have to be bitmaps, but can also include procedural maps (generated by a computer algorithm), reflection and environmental maps, bump and displacement maps and opacity maps.

¹⁷ 3D models created by the author (October 2002).

Figure 2.18 shows the difference image mapping makes to a 3D object. The model uses raster images that were taken using a digital camera from a real house and modified using image editing software and then draped over the 3D model.

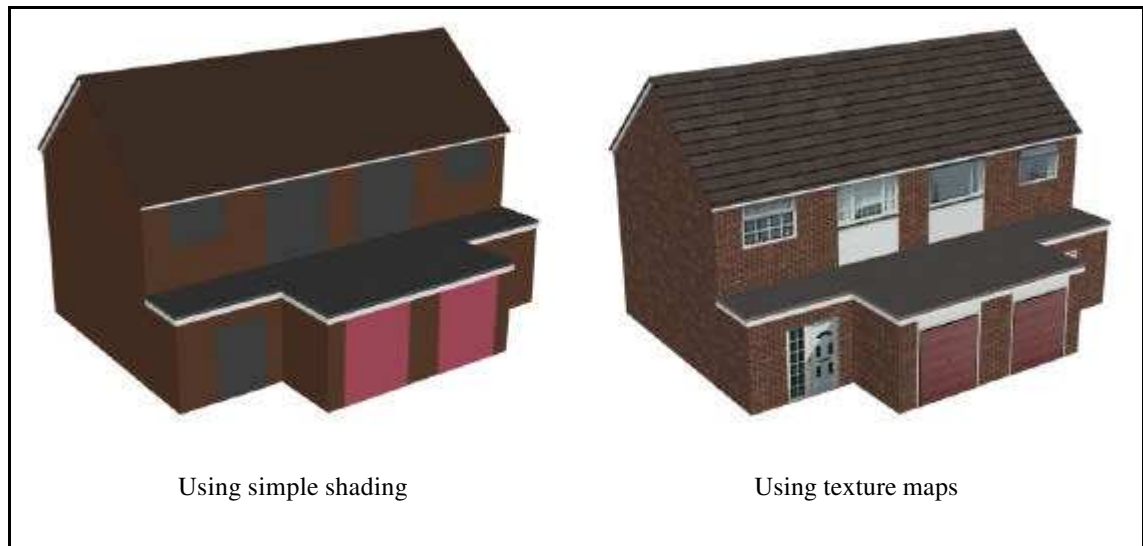


Figure 2.18: The use of image mapping¹⁸.

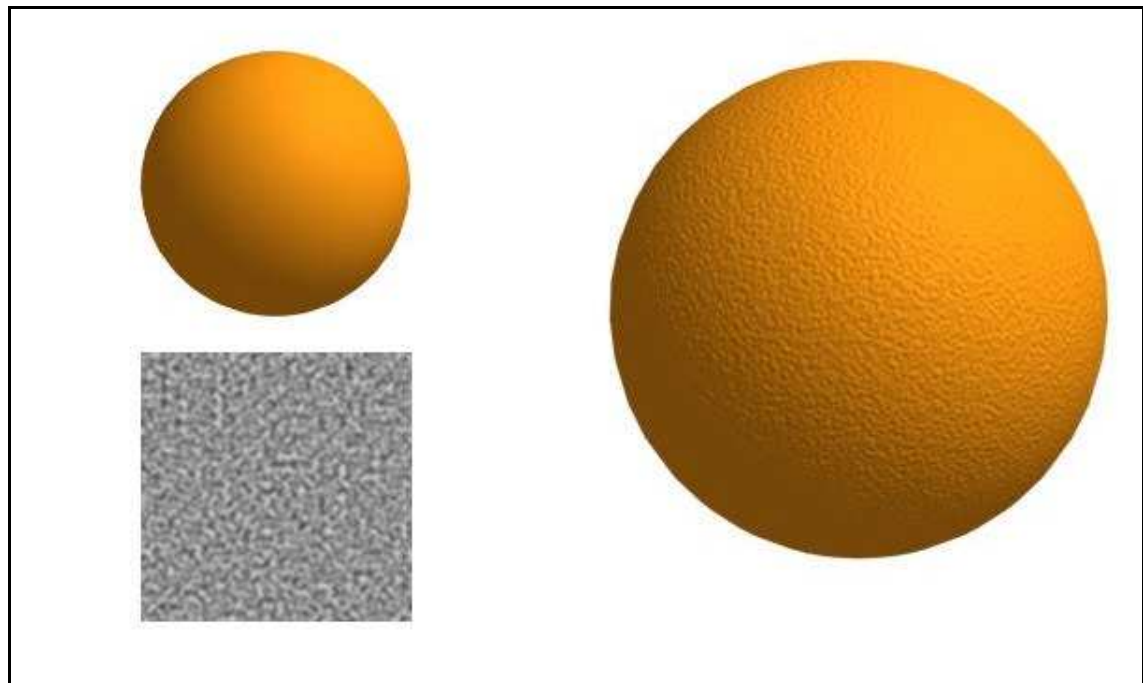


Figure 2.19: The use of procedural bump maps¹⁹.

¹⁸ 3D models created by the author for the Birmingham hospital case study (October 2002).

¹⁹ Images and 3D models created by the author (October 2002).

Figure 2.19 shows the use of bump mapping to turn a simple orange sphere (shown on the top left) into a view of a real orange (shown on the right) with a pitted surface. The bump map used was a procedural noise map (shown on the lower left) where the lighter (whiter) areas of the map appear to raise the surface and darker (black) areas appear to lower it due to the effect of shadows.

There are many different types of maps and a full detailed description is not within the scope of this thesis. Foley *et al.* (1994) and Watt (2000) describe many of the different types of maps used in 3D modelling in more detail.

2.2.5 3D Animation

This section reviews some of the basic concepts of animation, including fundamental techniques such as keyframing, motion paths and how models can be linked together to make the animation process less complicated.

2.2.5.1 Units of Animation and Animation Compression Techniques

Animations are made up of a number of frames (or still images). The number of frames that constitute one second of animation depends upon the output media, for example the standard frame rate for UK video is 25 fps (frames per second) while the standard frame rate for the United States of America is 30 fps (29.97 to be exact).

As with bitmap images, animations can be saved using a variety of file formats and compression techniques (commonly referred to as codecs) each with their own advantages and disadvantages. The most common animation file types include AVI, MPG, MOV, FLI and ASF and many of the various file types can use codecs to make animation file sizes smaller (similar to compression techniques used with still raster images). Common AVI codecs include the Cinepak Codec by Radius, Ligos Indeo Video and Microsoft Video 1. The two most common

codecs used by the MPG format include MPEG-1 and MPEG-2. A widespread application of MPEG-2 is that it is the codec used for films stored on Digital Versatile Discs (DVDs).

2.2.5.2 Keyframing

One of the fundamental techniques used in animation is called keyframing, which is used to define an animated sequence based on its key events. The key events are input into the animation software package at specific frames (called keyframes), and a technique called in-betweening (or tweening) is used to fill in the gaps between the key frames, this is done by the software using an interpolation technique. The in-between frames created are known as tweens.

Figure 2.20 demonstrates keyframing and the use of in-betweening to create tweens. A sphere was created with a radius of unit size 100 at frame 1 of the animation and a keyframe was created. The sphere was then duplicated to a unit radius size of 20 and placed 100 units away along the horizontal axis at frame 5 and a second keyframe was created. The software, in this case 3D Studio MAX, then interpolated between the 2 keyframes to produce frames 2 to 4 which show the sphere gradually shrinking in size as it moves along horizontally.

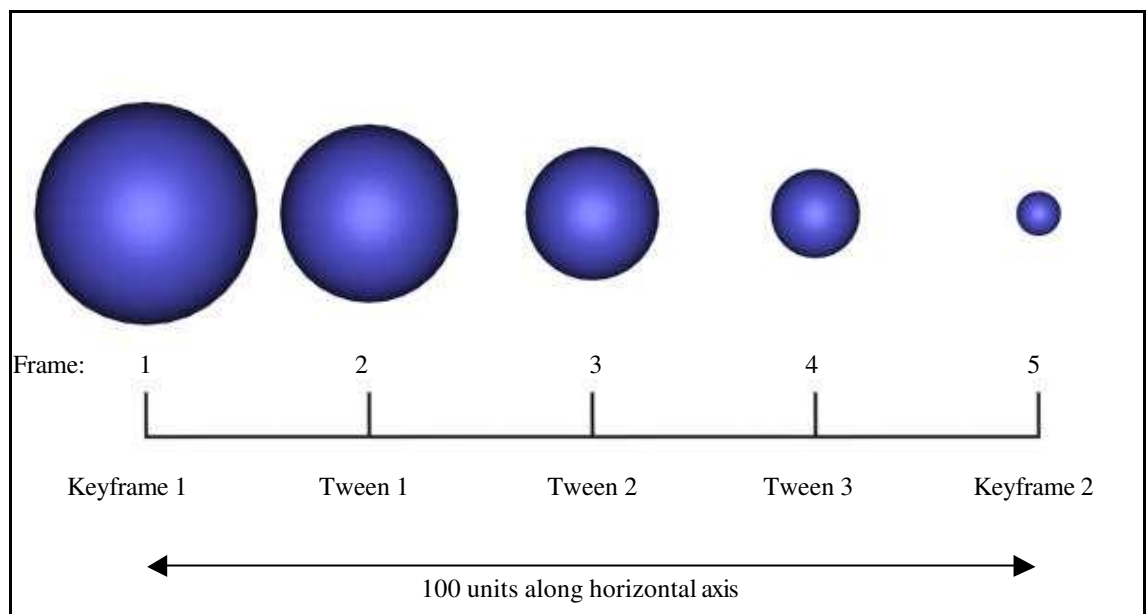


Figure 2.20: The use of keyframes for animating²⁰.

²⁰ Image and 3D models created by the author (October 2002).

2.2.5.3 Motion Paths

This animation technique uses a path in the 3D environment to define an objects position through time. For example, a car's motion path could be a spline with a series of curves which matches the bends of a road (figure 2.21).

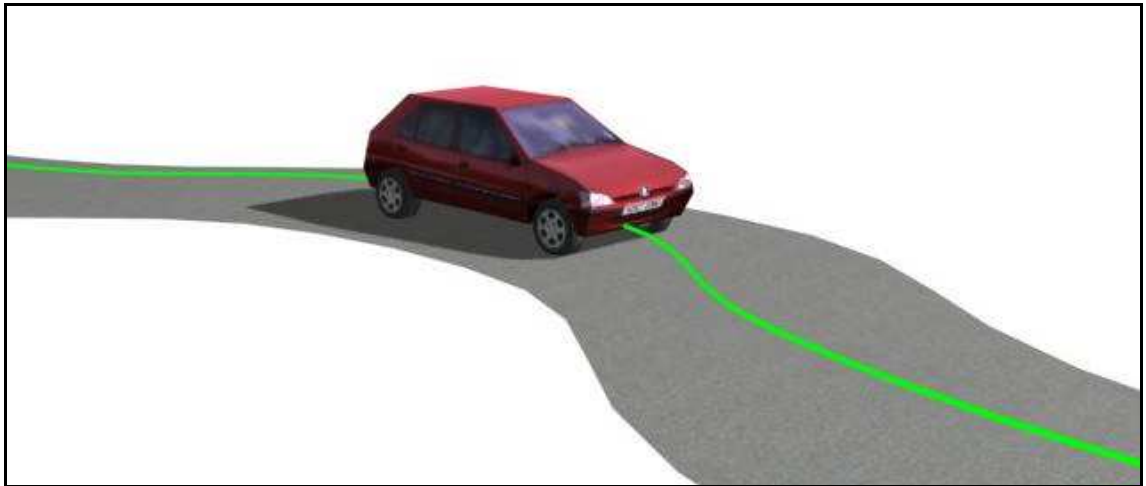


Figure 2.21: The use of a motion path to define a car's position through time²¹.

Kerlow (2000) describes a process of creating animations using motion paths:

“Motion path animation is defined in several steps, and it starts with a curve being drawn in three-dimensional space, usually with a curve modelling tool. Then the model to be animated is selected and linked to the path. The timing parameters of the path are then defined. This is usually done by typing the values of the frames in which the motion path animation is to start and end.”

2.2.5.4 Hierarchies and Kinematics

3D objects can be grouped together in order to define the ways in which these objects relate to one another and behave when animated. These types of groups are known as hierarchical structures and are useful for handling very large, multi, sub-shape models and manipulating

²¹ Image and 3D model created by the author (April 2003).

articulated models. Schofield (2000) states:

“When objects are linked together so that one object is superior, it controls the transformations of one or more subordinate objects. The linkage is unidirectional in that superior objects can control subordinates but subordinates have no effect on their superiors. This structure hierarchy often uses a tree analogy to describe the relationship between the objects linked together.”

There are many terms used in hierarchical structures and many of them are listed in table 2.3. Figure 2.22 shows an example tree hierarchy of the lower half of the human body. The thighs are children of the waist, the shins are children of their respective thighs, the feet are children of their shins and the toes are the children of their feet. Similarly, the waist is the parent of the two thighs, the thighs are the parents of their respective shins and so on.

Term	Description
Parent	Object that controls one or more children. A parent is often controlled by another superior parent object.
Child	Object controlled by its parent. A child object can also be a parent to other children.
Ancestors	Parent and all of the parent’s parents of a child object.
Descendants	Children and all of the children’s’ children of a parent object.
Hierarchy	Collection of all parents and children linked together in a single structure.
Root	A single parent object that is superior to all other objects in the hierarchy. All other objects are descendants of the root object.
Subtree	All the descendants of a selected parent.
Branch	Path through the hierarchy from a parent to a single descendant.
Leaf	Child object that has no children of its own.
Link	Invisible connection between a parent and its child. The link is a conduit for transmitting position, rotation, and scale information from parent to child.
Pivot	Defines the local centre and co-ordinate system for each object. Links connect the pivot of a child object to the pivot of its parent.

Table 2.3: Terms to describe hierarchies (adapted from Schofield, 2000).

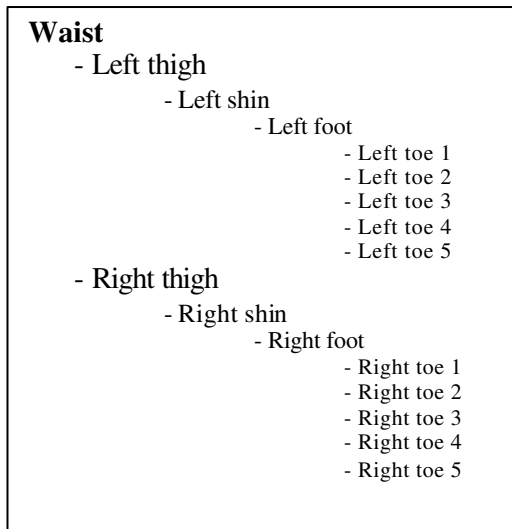


Figure 2.22: Example tree hierarchy of the lower half of the human body²².

A simplified graphical example of this hierarchical structure is shown in figure 2.23, where the thigh is considered as the root object, the shin as the child of the thigh and the foot as the child of the shin. Rotating the thigh would rotate all of the children in relation to the thigh (figure 2.23b), rotating the shin about the knee joint would relatively rotate the foot but not rotate the thigh (figure 2.23c) and rotating the foot about the ankle

would only rotate the foot and not affect any of its parents (figure 2.23d).

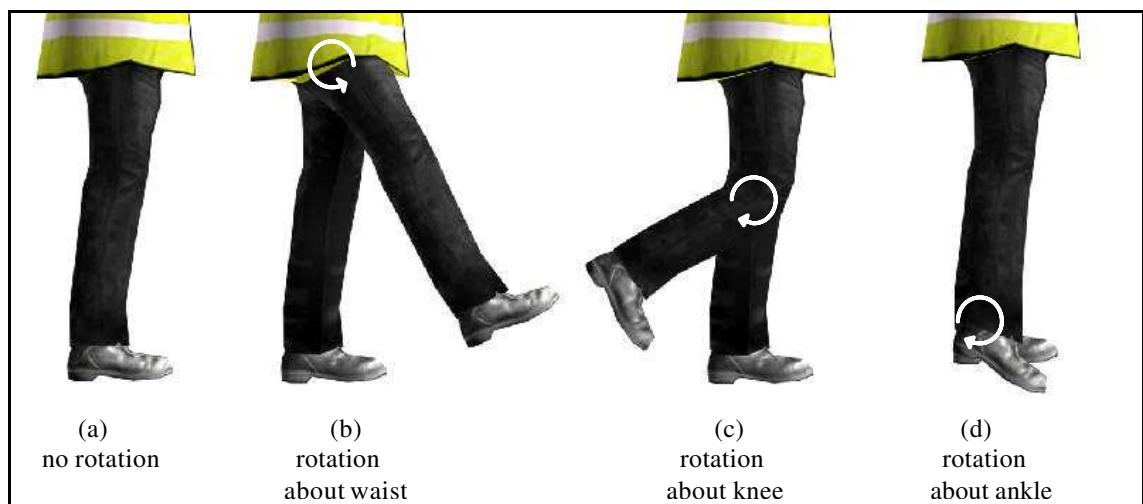


Figure 2.23: Example hierarchy of the human leg²³.

The animation employed in figure 2.23 is an example of forward kinematics, that is, once two objects are linked together, the child object maintains its position, rotation and scale transformations relative to the parent object. The animator begins by positioning parent objects and works down the hierarchy positioning each child object.

²² Tree Hierarchy by the author (October 2002).

²³ Image by the author (November 2002) from a 3D model created by Mr. T. Gilbert for AIMS Solutions Ltd. (2002).

Inverse kinematics works in the opposite manner. This is an animation technique where the animator positions objects at the end of the linkage and the software calculates the positions and orientations of all other objects in the linkage. This type of animation is used extensively in character animation.

2.2.6 Rendering

Rendering is a term that describes the process of shading 3D geometry using the cameras, lighting, materials and environment settings that have been defined. This section briefly describes the rendering process, the various rendering methods that can be used and the different rendering options available.

2.2.6.1 The Rendering Process

The rendering process consists of a number of separate processes (Schofield, 2000):

- ?? Set up a data structure for the polygon models that will contain all the information which is subsequently required in the shading process.
- ?? Apply linear transforms to the polygon mesh model such as transformations to position objects within a scene and viewing transformations.
- ?? Culling back face polygons (the process of discarding unseen polygons).
- ?? Scan converting or rasterising polygons (converting vertex-based models into a set of pixel co-ordinates).
- ?? Applying hidden surface removal algorithms.
- ?? Shading the individual pixels using an interpolative or incremental shading scheme.

Because of the complex and cumulative nature of the rendering process, the last three steps are usually carried out simultaneously.

2.2.6.2 Rendering Techniques

There are a number of rendering techniques that can be used, either on their own or a

combination of methods. Example techniques include the Z-Buffer, ray tracing and radiosity rendering methods.

The Z-Buffer method uses a buffer to store depth information of objects in the virtual scene. This depth information is then used to determine which pixels of each object are closest to the camera. If the pixel is closest to the camera then it can be seen and hence shaded accordingly. This type of rendering method can be quite efficient, but may discard some of the 3D information that can be used for shadowing, texturing and antialiasing enhancement (Kerlow, 2000).

Ray tracing creates a ray for each pixel on the screen and traces its path from the camera to the light source. The advantage of this method is that the rays are able to deal with processes such as reflections and transparency. The method is also precise when simulating the behaviour of light in 3D space and can sometimes produce high quality photorealistic results. However, this technique requires a large amount of processing power and it can take a long time to render a 3D model.

Radiosity rendering techniques are based on the principles of illumination engineering theory and energy transfer. This method produces unparalleled diffuse interreflection calculations between surfaces (Kerlow, 2000). As with ray tracing however, a large amount of computer memory and raw computing power may be required for these calculations.

2.2.6.3 Rendering Options

There are a number of rendering options available and these vary between software packages. The particular options which relate to the work in this thesis include anti-aliasing, filter maps and image and motion blur. Anti-aliasing has been described earlier and is used to soften the jagged edges of objects. Similarly, filter maps can be used to sharpen or soften the final output.

Turning off anti-aliasing and filter maps may speed up the rendering but the final output may have a blocky feel. Image and motion blur are often used to add realism to a computer animation, they simulate the blurring effect that would occur when filming fast moving real objects with a camera. Image blur works by smudging the object with a smear effect, whilst motion blur works by rendering multiple copies of the object in between frames and then rendering them together.

2.3 Example 3D Model

To further explain the 3D modelling techniques and methods, the following section describes the processes used to create the lamp shown in figure 2.24 which is part of a bedroom scene which was modelled by the author using 3D Studio MAX.



Figure 2.24: A bedroom scene modelled using 3D Studio MAX²⁴.

²⁴ 3D model created by the author (August 2001).

2.3.1 Modelling the Geometry

The modelling of the geometry has been split into two sections, the first section describes the basic geometry used, and the second details the modifications made to the geometry. Figure 2.25 shows the modelling steps used to create the lamp.

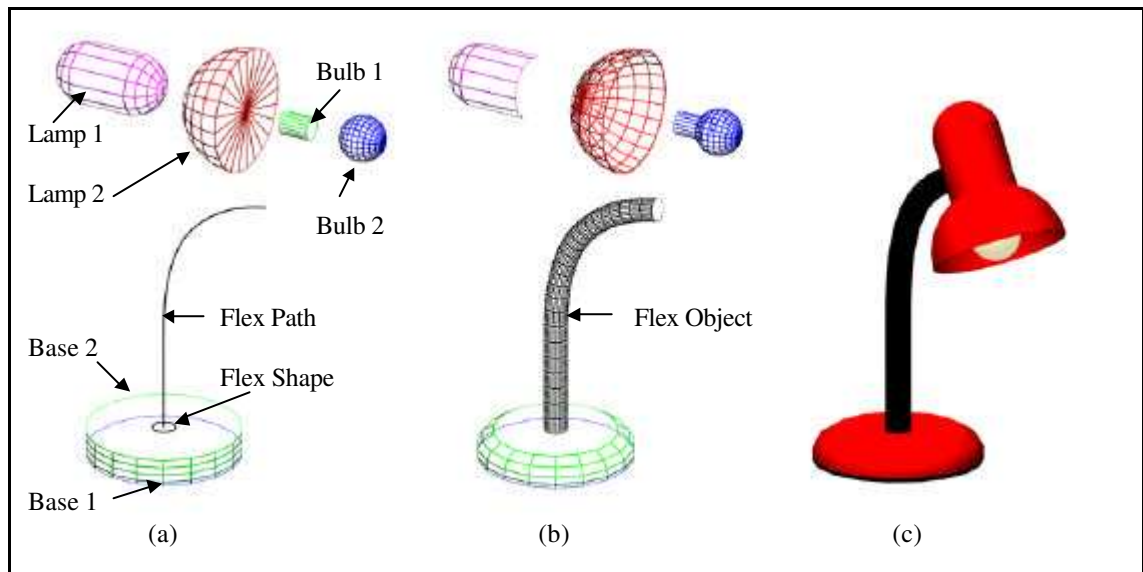


Figure 2.25: Step by step process of creating lamp model²⁵.

2.3.1.1 Basic Geometry

Two cylinders were created and named Base 1 and Base 2, with 1 and 3 height segments respectively. An “OilTank” primitive (a standard object model included with the 3D CG modelling software) was then created and named Lamp 1, a hemisphere named Lamp 2, a cylinder named Bulb 1 and a sphere named Bulb 2. The flex portion of the lamp is made using two splines, Flex Path, which is a simple curved line and Flex Shape, which is a circle. Figure 2.25a shows the original geometry that was created.

²⁵ Image by the author (October 2002).

2.3.1.2 Editing the Geometry

Bulb 1 and Bulb 2 were attached to each other to form one object and the end faces of Lamp 1 were deleted. The vertices of Base 2 were scaled in layers along the x and y axes (on a horizontal plane) to give the base some curvature. The Flex Shape was lofted through the Flex Path to form the solid Flex Object. The lamp cone was created by cloning Lamp 2 and resizing the clone so that it was slightly smaller than its original. A Boolean subtraction was then performed on Lamp 2 and its clone. Figure 2.25b shows the lamp after the modifications. The lamp objects were then moved to their correct positions.

2.3.2 Shading

The metal lamp parts were shaded using a Phong shader with a red tint. This gives the lamp a specular reflection. The black portions of the lamp were given a black matt colour using a Blinn shader. The light bulb was coloured white with a yellow tint and given self illumination so it appears as though it is switched on and glowing. Figure 2.25c shows a rendered image of the lamp with shading applied.

2.3.3 Lighting and Shadows

A target spotlight was added at the bulb's co-ordinates and direction with a hotspot of 60 units and falloff of 80 units. A volume light effect was then added to the spotlight with a density of 200 units and given the same colour as the bulb in order to produce a spotlight glow.

An omni light was also added to illuminate the lamp from above and to the right simulating low levels of external lighting, such as from a separate room light. A plane was created for the lamp to sit on to show the lighting and shadow effects more clearly. A second omni light was added at the bulb's position and configured to illuminate only the inside of the lamp, all other objects were excluded from its lighting effect. Figure 2.26 shows a finished rendered image of the lamp.



Figure 2.26: Rendered image of finished lamp model²⁶.

2.4 Introduction to Virtual Reality

2.4.1 Definition

VR is a CG technology, relying on computer hardware and software to generate virtual worlds which can be interacted with in real-time via visual and other sensory outputs. VR cannot easily be defined since it encompasses an enormous spectrum of activity. However, Vince (1998) makes the following definition:

“VR is about using computers to create images of 3D scenes with which one can navigate and interact. By navigate we imply the ability to move around and explore features of a 3D scene such as a building; whilst interact implies the ability to select and move objects in a scene, such as a chair.”

In most general definitions, VR is the ability to interact with objects and other users in an

²⁶ 3D model created by the author (Oct 2002).

artificial computer generated environment. VR systems render 3D environments in real-time, allowing the user to move around virtual worlds, interacting with objects and other users, which all give the user a sense of physically “being there”.

Prime examples of VR are popular 3D computer games such as “Return to Castle Wolfenstein”, by Gray Matter Interactive Studios (2002), a screenshot of which is shown in figure 2.27. The games render 3D environments in real-time, allowing the user to interact with a number of objects in the world. Realistic lighting and sound effects, coupled with detailed models and animation, give these 3D games a sense of realism and immersion.



Figure 2.27: Screenshot of Return to Castle Wolfenstein²⁷.

2.4.2 History of Virtual Reality

The term VR came from Jaron Lanier, the founder of VPL Research (Beier, 2001). However, it was in 1965 that Ivan Sutherland published a paper entitled “The Ultimate Display” which described how one day, the computer would provide a window into virtual worlds. In 1968,

²⁷ Image from Activision (2002).

Sutherland went on to create one of the first Head Mounted Displays (HMDs) that provided stereo views of a CG 3D scene (Vince, 1998).

VR remained relatively dormant in the 1960s and 1970s due to the high cost and low power of computers. The 1980s saw a growth in VR due to the new computer technology being developed. The improvements in computing power have allowed virtual worlds to be modelled and images of these worlds to be generated in real-time. As the graphics technology has improved so has the quality of the displayed images and refresh rates similar to that used by television can be maintained (Vince, 1998 and Williams, 2000).

2.4.3 Types of Virtual Reality Systems

There are several different types of VR systems which use different technological devices and perform different functions. Below are examples of some of the various types of VR systems.

2.4.3.1 Simulation Systems

Simulation systems are the most sophisticated VR systems requiring the viewer to be completely enclosed in a capsule, possibly mounted on a motion platform, with high resolution computer screens and surround sound. The experience can seem quite real and is often used to train aircraft pilots and tank drivers for example. Figure 2.28 is an example of a flight simulator used to train aircraft pilots.



Figure 2.28: Flight simulation system²⁸.

²⁸ Image from Aerospace Industries (2002).

2.4.3.2 Immersion Systems

Immersive systems require the user to wear a HMD that tracks the users head movements which then changes the view accordingly (figure 2.25). This type of VR system encases the audio and visual perception of the user in the virtual world and cuts out all outside information so that the experience is fully immersive. The technology is fairly expensive and has a number of disadvantages including low resolution images, encumbrance and occasional simulator sickness.



Figure 2.29: A typical HMD²⁹.

2.4.3.3 Projection Systems

This type of VR system uses large projection displays to create an immersive room for users to stand or sit. The advantage of this type of system is that a number of users can view the virtual world at the same time.

A CAVE, an acronym for Cave Automatic Virtual Environment, is a type of VR projection system. Vince (1995) describes how a CAVE works:

“A CAVE enables one or more persons to experience the sensation of being completely

²⁹ Image from SAVE (2000).

surrounded by high-resolution, 3D video and audio. It is a room formed from three rear-projection screens for walls and a down-projection screen for the floor. High-resolution video projectors display computer-generated, stereo images while computer-controlled amplifiers relay sampled sound through a network of speakers. Inside a CAVE, a user wears a pair of stereo shutter glasses to select the left and right images... ..and the viewpoint is determined by tracking equipment worn on the user's head and hand.”

Typical applications for VR projection systems include interactive molecular modelling, scientific visualization, sound simulation, architecture, weather simulations and medical modelling (Vince, 1995).

2.4.3.4 Desktop Systems

The most widely used VR system is the desktop system which consists of a conventional computer monitor to display the virtual world. Although these systems provide a lower level of presence and possibly interaction, they can achieve greater graphics quality, user comfort and convenience and lower costs. This type of VR system is best demonstrated by first person computer games such as Return to Castle Wolfenstein as described earlier.

Typical input devices include the mouse, keyboard and joystick, while output devices include stereo speakers and a monitor, however, the use of 3D or shutter glasses can give an extra dimension to the virtual worlds.

2.4.3.5 Augmented Reality

An augmented reality system generates a composite view for the user, whereby information such as text, graphs and images are projected onto a transparent screen still allowing the user to view the real world.

Figure 2.30 shows an augmented reality image created using a prototype system developed by the University of Nottingham. The image shows the location of underground pipes and cables which were overlaid in real-time over a view of a high street. Roberts *et al.* (2002) describe an advantage of augmented reality in this particular field:

“It can facilitate the work of engineers and managers in the field and reduce the costs of field excavations and other operations.”



Figure 2.30: Augmented reality image of underground pipes and cables³⁰.

2.4.4 Applications of Virtual Reality

There are a wide and varied range of VR applications and many of these were briefly mentioned in section 2.1.3. Below, however, are a few of those VR applications in more detail.

³⁰ Image from Roberts *et al.* (2002).

2.4.4.1 Medicine

VR can be used in the field of medicine for a variety of tasks including computational neuroscience, molecular modelling, treating phobias and ultrasound echography (Vince, 1995). Other medical application areas include VR training simulations which can be used to develop surgeons surgical skills, the main advantage being that no harm will come to animals or humans. Also, augmented reality systems have been used for neurosurgery to graphically visualise patient data (figure 2.31).

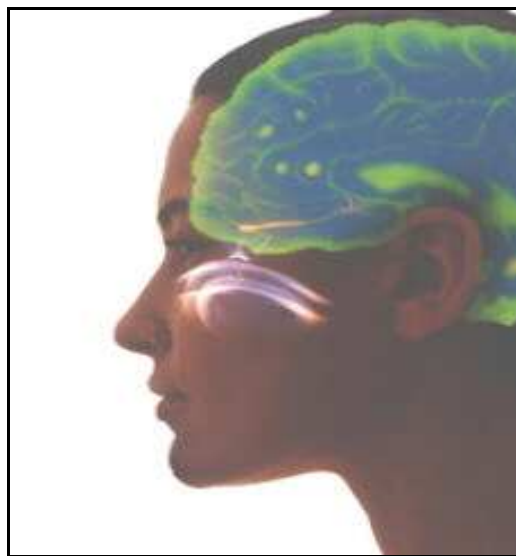


Figure 2.31: Simulated augmented reality medical image³¹.

Other medical applications are described by McCloy and Stone (2001):

“A wide range of virtual reality training systems have been developed, but not all are widely available yet. A commercially available simulator for venepuncture has force feedback to simulate the feel of the cannula entering the skin and vein. This is suitable for training nurses, medical students, phlebotomists, and paramedics. More complex simulators for therapeutic gastroscopy, endoscopic retrograde cholangiopancreatography, and colonoscopic procedures are available for trainees in gastroenterology.”

³¹ Image from Vallino (2002).

2.4.4.2 Education and Training

VR has long been used for education and training and various simulators have been developed for all kinds of tasks such as the operation of planes, submarines, power plants, tanks, helicopters, ships, cranes, trains, surgery, cars and air traffic control. Figure 2.32 shows a view of an absorption column VR simulation trainer, developed as part of a Ph.D. by Nasios (2001), that lets students undergo experiments in a safe environment. Vince (1995) explains the benefits of such VR simulations:

“Training through simulation provides significant benefits over other methods. For example, a hazardous environment, such as a nuclear power station, or an aircraft landing in fog can be accurately simulated without any danger to the trainee. Computer software provides the flexibility to structure training programmes and even monitor and measure the progress of a training session. Because simulators are so forgiving in the way they tolerate mistakes, trainees can experience first-hand why certain procedures must not be used in the real world.”

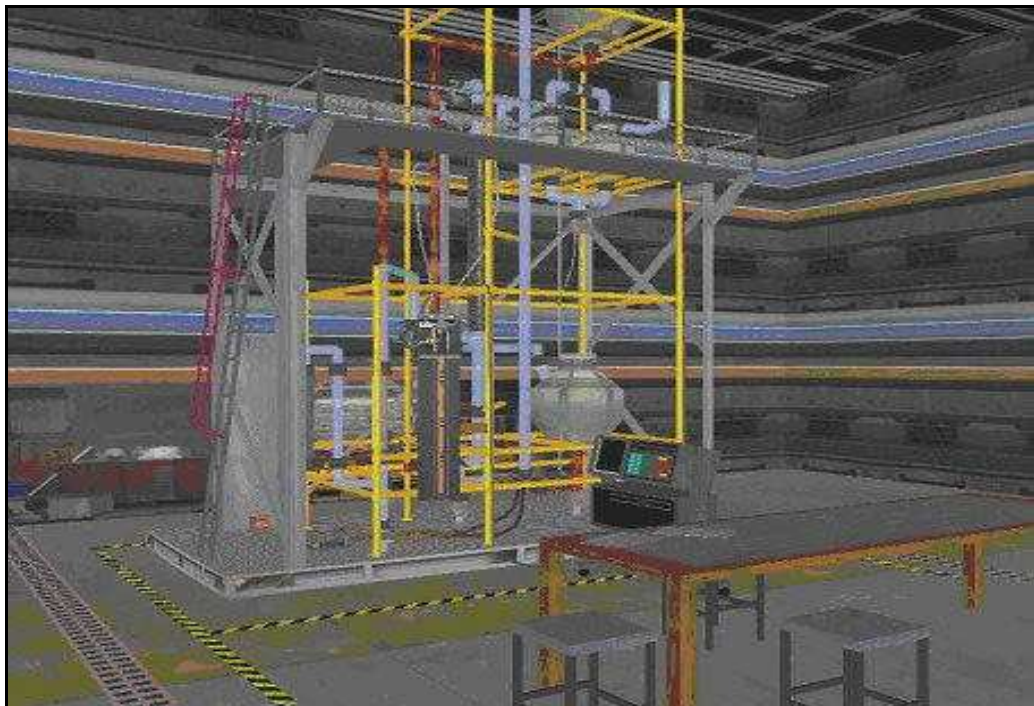


Figure 2.32: Absorption column VR simulation trainer³².

³² Image and 3D model by Nasios (2001).

One of the best known VR simulators is the flight simulator which is heavily relied upon by military aviation and commercial airlines (figure 2.28). To achieve a realistic simulation, the simulator must “look and feel” like a real aeroplane which requires that the simulator incorporates a cockpit identical to that used in reality including such items as working instruments, force-feedback joysticks and hydraulic platforms.

2.4.4.3 Entertainment and Sport

The use of VR in the games industry is widespread and has been previously mentioned. VR, however, can also be used in sport, for example, a round of golf can be played using large projection screens in which the golfer must direct his ball towards a virtual green (figure 2.33).



Figure 2.33: VR golf simulator³³.

Cyclists can also use VR techniques to improve their visual experience when using cycling machines by using large projection screens which update the display according to the speed of the cyclist.

³³ Image from Golf-a-Round America (2002).

Television cartoons are starting to make use of real-time VR, for example, the BBC's Ratz the Cat, from a children's television program, is animated in real-time during a live broadcast using a tracking system on the puppeteer (Vince, 1995).

2.4.4.4 Engineering and Architecture

Before the use of VR in the engineering field, descriptions of engineering components were viewed as lifeless drawings or static perspective projections some of which were animated along a set path through a 3D model. VR has enabled components to be virtually manufactured, inspected, assembled and tested without the need for expensive and time consuming prototype production.



Figure 2.34: Architectural walkthrough of a studio³⁴.

³⁴ Image by Artifice, Inc. (2003).

Architects can use VR to take themselves, or their clients, for a walk through the rooms or buildings they are designing (figure 2.34). This allows the architect and client to get a real feel for the design and allows for possible design changes to be visualised. The advantage of using VR for walkthroughs instead of CG animations is that the viewer is not restricted to a set path, they can explore the virtual design freely.

2.4.4.5 Data Visualisation

Data visualisation is the use of graphical representations of information to make certain characteristics or values more apparent. This is especially the case for visualising complex 3D data sets such as those arising from Computational Fluid Dynamics (CFD) calculations.



Figure 2.35: VR visualisation of smoke from a burning car³⁵.

Data is usually visualised by mapping geometric objects, such as arrows or particle clouds, to the data values. For example, to visualise air flow, arrows could be mapped to the data values

³⁵ Image taken from 3D model created by Mr J. Noond for AIMS Research (2001).

where their width could represent volumetric flow rate, colour represents temperature and direction represents the direction of air flow.

Figure 2.35 shows a 3D visualisation of a cloud of smoke arising from a burnt out car situated in an underground car park. The user can navigate and interact with the environment and view the smoke at various time intervals. Such data may not be easily visualised by the layperson using 2D plans or static 3D representations.

2.4.5 Virtual Reality Software

There are two main types of VR software available; toolkits and authoring systems. Toolkits are programming libraries that provide a set of functions with which a skilled programmer can create VR applications. Authoring systems, however, are programs with graphical interfaces for creating VR worlds without resorting to detailed programming (Schofield, 2000). There are a number of VR toolkits and authoring software applications available and a few are briefly described below, ranging from software packages that are free to use to those that are expensive.

2.4.5.1 Free of Charge Software

Software products that are free (commonly referred to as freeware or shareware) are generally copyrighted and commercial use is often restricted. Examples include Alice (Carnegie Mellon University, 1999), DIVE (SICS, 2002), Meme (Immersive Systems Inc., 2002) and the popular Virtual Reality Modelling Language (VRML).

VRML is often used to create, distribute and present simple VR worlds on the internet. It is an open, extensible, industry standard scene description language. Nasios (2002) describes VRML in more detail and provides some examples of its use.

2.4.5.2 Inexpensive Software

There are a number of commercial VR programs that sell for under £200. Computer games can be considered in this category and are currently at the forefront of VR technology. The games can feature realistic graphics and sound, interaction and are distributed cheaply and are used by millions of people. 3D editors are also available which allow players to modify and even create their own 3D worlds for these game environments.

As well as computer games, other inexpensive packages include ThemeKit (Themekit Systems Ltd., 2000) and DarkBASIC (Dark Basic Software Ltd., 2002), which is primarily an amateur's game creation software package.

2.4.5.3 Moderately Expensive Software

Mid-range products can be considered as those under a £1000 which do not require any specialised hardware beyond the basic computer system. There are some excellent professional packages in this price range, three of which are World Tool Kit (Sense8, 2001), which is a toolkit consisting of a library of programming functions, Virtual Reality Toolkit (Superscape, 2001) which is an authoring package and Macromedia Director Shockwave Studio (Macromedia, Inc., 2002).

2.4.5.4 Expensive Software

Beginning at £1000, these VR software packages are typically aimed at the professional market and can often require a high specification computer, namely a workstation or Silicon Graphics, Inc. (SGI) system. These high-end packages often require extremely expensive hardware, such as those used in flight simulators.

Packages include EON Studio and EON Immersive (EON Reality, Inc., 2002) and EaSIEST and

INTEGRATOR (Evans & Sutherland, 2002a and 2002b). These high-end packages are usually aimed at industry, for simulating a product's functionality before production for example, or for training applications, especially those used by government organisations for application areas such as flight simulators, gunnery training, and space shuttle training.

Dr. Robin Hollands at the University of Nottingham has developed Safe-VR, a VR authoring package which does not require any special hardware. This and other software used in this thesis is described in more detail in appendix 1.

2.4.6 Benefits and Limitations of Virtual Reality

2.4.6.1 Benefits

The main advantage of VR is that it can immerse people in an environment that would normally be unavailable due to cost, safety, or perception restrictions. This is agreed and expanded upon by Williams (2000):

“VR allows us to see worlds that are modelled inside computers and to experience things that are not normally accessible in real life or perhaps not yet created. The laws of these worlds are not physically bounded and can have as many or as few constraints as one wishes.”

Other benefits are listed below (Kalawsky, 2000):

- ?? Observation of system features that would be either too small or too large to be seen on a normal scale system.
- ?? Achieve a sense of non real-time; where situations can be presented in slow or fast time.
- ?? Achieve a high degree of interaction that can equal or exceed that achievable in the real world.
- ?? Repeat the task until the desired level of proficiency or skill has been achieved.
- ?? Perform in a safe environment.

- ?? Ability to observe virtual world from a number of views.
- ?? Training simulations can be performed off site, even in different countries.

2.4.6.2 Limitations

The main feature of VR is that the user can interact with the virtual world in real-time, which requires that the computer processes the world in real-time and at an acceptable frame rate so as to achieve a smooth and responsive simulation.

In order to achieve a smooth and responsive VR simulation either the complexity of the virtual world may have to be decreased so the computer can process the data quickly enough, or the computer itself may be upgraded to a specification high enough to cope with the requirements of the simulation. This second option may not be feasible for many people who are on a limited budget, so developers generally tend to make their VR simulations as least demanding on computer processors as possible.

The complexity of a virtual world can be decreased using two methods. The first way is to budget the number and size of textures used. The second method is to budget the number of faces or polygons in the 3D models which make up the virtual world. This is usually achieved by removing hidden faces and those faces which are unnecessary in attaining a model's shape (for example, a box that is made of twenty-four polygons could be made using only six polygons). This process is generally referred to as polygonal simplification or optimisation. A skilled developer should be capable of producing an efficiently textured and low polygon world while still maintaining an accurate representation of the real world environment.

2.5 Virtual Reality Example

The following section describes the processes used to create a VR world of a typical domestic kitchen with a number of hazards (figure 2.36). 3D Studio MAX was used to model the

geometry, Gamut-DXm (Animetix Technologies, Inc., 2001) was used to convert the scene to the DirectX file format employed by Safe-VR, and Safe-VR was used to create the interactive environment.

2.5.1 Importing Objects

Using Gamut-DXm, individual 3D Studio MAX objects, such as the cooker, the washing machine and cupboards, were exported to the DirectX “.x” file format and then imported into Safe-VR. Sound files, which represented squeaky doors opening and the user treading on water, were also imported and linked to their associated objects. Various objects which have been classed as potentially hazardous, such as chemicals, spilt water and the boiling pot, were identified as hazards within the software.



Figure 2.36: VR kitchen with a number of hazards³⁶.

³⁶ Image from a 3D model created by the author (March 2002).

2.5.2 Interaction with Objects

A number of simulation modules were created that store data about the interaction of objects, sounds and hazards with each other and the user. Figure 2.37 shows two Safe-VR simulation modules, the lower left module is used to interact with the kitchen drawers and the upper right module is used to interact with the spilt water and also to class it as a hazardous object.

The drawers module lets the user to double click on any drawer. Once clicked, a drawer sound will play and the drawer will open or close. Flags (boolean variables) are used to identify if the drawer is open or closed. If the drawer is already open, then double clicking on the drawer will close it and vice versa. The spilt water module (named TreadOnWater) has two sections of code. The first section is used to play a sound file, that simulates treading on water, when the user walks over it. The second section is for spotting the water hazard and is covered in more detail below.

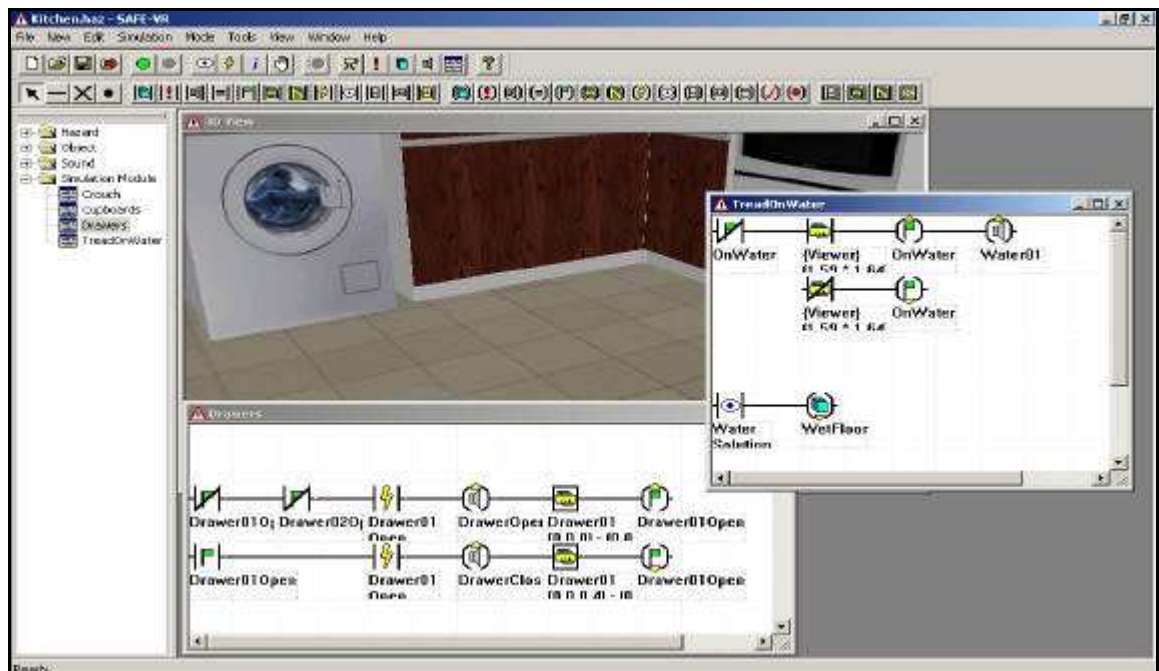


Figure 2.37: Safe-VR simulation modules³⁷.

³⁷ Image of 3D model from a VR environment created by the author (October 2002).

2.5.3 Creating Hazards

Various objects which have been classed as potentially hazardous, such as chemicals, spilt water and the boiling pot, were given hazard properties which detail the hazard and possible remedies for the hazard. For the spilt water, two possible solutions were identified (one correct and one incorrect), either mop it up or leave it alone. When the user clicks on the water and identifies it as a hazard, the user must select which solution is appropriate (figure 2.38). The second piece of code for the spilt water module is used to hide the water if the user picks the correct solution, in this case mopping it up.



Figure 2.38: Hazard spotting³⁸.

When the user is confident that they have identified all possible hazards and correctly remedied them then the VR simulation can be stopped. A summary of the user's performance is given, identifying any missed hazards and incorrectly remedied solutions.

³⁸ Image of 3D model from a VR environment created by the author (October 2002).

2.6 Summary

This chapter has provided a brief history and technical background to CG and VR and some of the applications of these technologies. It has been shown that the price of CG and VR software varies to a great extent providing both novice and professional users with a platform to develop images, animations and simulations for a variety of tasks including design, accident reconstruction, data visualisation, entertainment, medicine and training.

The advantages and disadvantages of CG and VR over non-computerised techniques in a range of user areas have also been discussed. Two distinct advantages of CG are editability and repeatability. That is, changes can be made efficiently and data can be duplicated to ease repetitive work. Other advantages of CG include speed, accuracy, consistency and the ability to visualise complex data without difficulty and to view objects in both 2D and 3D. Disadvantages include computer fallibility, file incompatibility and the possible user training that is required to operate the software packages.

The main advantage of VR is that it can immerse people in an interactive environment that may be unavailable due to cost, safety and perception restrictions. Another advantage is that it is possible to visualise and interact with an environment that may not have been, or cannot be, created in the real environment. The main disadvantages are due to limitations in computer processing power that can lead to lower frame rates in the simulations.

This thesis is concerned with the application of the technical disciplines from this chapter to EIA. Chapter 3 provides some background information on the EIA process and what it aims to achieve, its legislation in the UK and a brief description of the current EIA process. The chapter will also explore VIA, a subset of EIA, in more detail including current and earlier techniques used to produce VIAs.

3 Assessing Environmental and Visual Impact

3.1 Environmental Impact Assessment

3.1.1 Introduction

The term EIA has no fixed definition, but the Department of the Environment (1989) define EIA as:

“...a technique and a process by which information about the environmental effects of a project is collected, both by the developer and from other sources and taken into account by the planning authority in forming their judgements on whether the development should go ahead.”

DOEWO (1990) describe EIA as:

“...an important technique for ensuring that the likely effects of new development on the environment are fully understood and taken into account before the development is allowed to go ahead.”

Since 1970, EIA has been internationally recognised as an environmental management tool (IEATLI, 1995). The purpose of an EIA is to provide decision makers with environmental analysis, establish alternatives, improve the design of a development and to provide a source of information to the public and other parties with the opportunity for consultation.

The development of the EIA process came about from a number of factors including the failure of traditional project appraisal techniques (such as cost-benefit analysis), the growth of environmentalism and the impact of unforeseen environmental changes on the efficiency and profitability of many projects.

An EIA is usually performed by the developer of the project in question, although it can often

be carried out by environmental consultants. EIAs are broad in scope encompassing a wide range of disciplines which deal with different categories of environmental impacts or effects. These can be grouped into four main categories; pollution and ecological, natural resource, social and economic. These categories are described in more detail by Gilpin (1995). Typical environmental impacts include:

- ?? ground contamination
- ?? water contamination
- ?? air contamination
- ?? noise
- ?? landscape and visual

Typical environmental effects include:

- ?? ground pollution
- ?? water pollution
- ?? air pollution
- ?? modification of ecology
- ?? loss of cultural heritage
- ?? economic loss
- ?? increase in traffic
- ?? increase in noise
- ?? loss of aesthetic quality
- ?? climate change

Environmental effects are defined as the result of environmental impacts, both man made and naturally occurring. Impacts need to be carefully researched to keep environmental effects to a minimum, and this is a key role of an EIA.

3.1.2 Current Legislation

In 1985 the European Union (EU) adopted the first Directive on EIA (EC Directive 85/337/EEC), which was implemented in the UK through the Town and Country Planning

(Assessment of Environmental Effects) Regulations 1988 (European Council, 1985; British Medical Association, 1998; DOEWO, 1990 and IEATLI, 1995). The Directive was intended to ensure that any projects, both public or private, likely to have significant effects on the environment were subject to EIA before development consent was authorised.

The 1985 Directive was subsequently amended in 1997 by EC Directive 97/11/EC in order to improve many of the requirements of the original Directive, particularly with regard to whether projects should be subject to an EIA (Bond, 2000 and British Medical Association, 1998). This is implemented in England and Wales by the Town and Country Planning (England and Wales) (Environmental Impact Assessment) Regulations 1999 (LITIEMA, 2002).

UK regulations divide projects into two categories; Schedule 1 projects and Schedule 2 projects. The EC Directive 85/337/EEC defines Schedule 1 projects as projects which automatically require an EIA due to the significance of their potential impacts on the environment. This includes oil refineries, nuclear power stations and integrated chemical installations (British Medical Association, 1998). Schedule 2 projects, which include agriculture, extractive industries, energy industries and wood and paper industries only require an EIA if they are judged likely to have significant environmental effects (Bond, 2000). Annex I and II in the EC Directive 85/337/EEC give a full description of Schedule 1 and 2 projects and Annex III describes the criteria for an environmental effect to be significant.

The majority of development in the UK tends to be dealt with under the Town and Country Planning Acts and related regulations. However, LITIEMA (2002) states that:

“...EIA is also a requirement for various types of development or activity falling within the ambit of other regulations, including forestation, land drainage improvement works, highways, pipelines, harbour and electricity works.”

3.1.3 The Environmental Impact Assessment Process

Throughout the world there are many diverse approaches to EIA, and neither the EC Directive nor the regulations prescribe any particular methodology to be used in carrying out an EIA (LITIEMA, 2002). However, these different approaches share common elements and figure 3.1 shows a generic flowchart of the EIA process. It has been broken down into simple stages, in reality the process is often much more complicated. Some of the different EIA stages are described below in more detail.

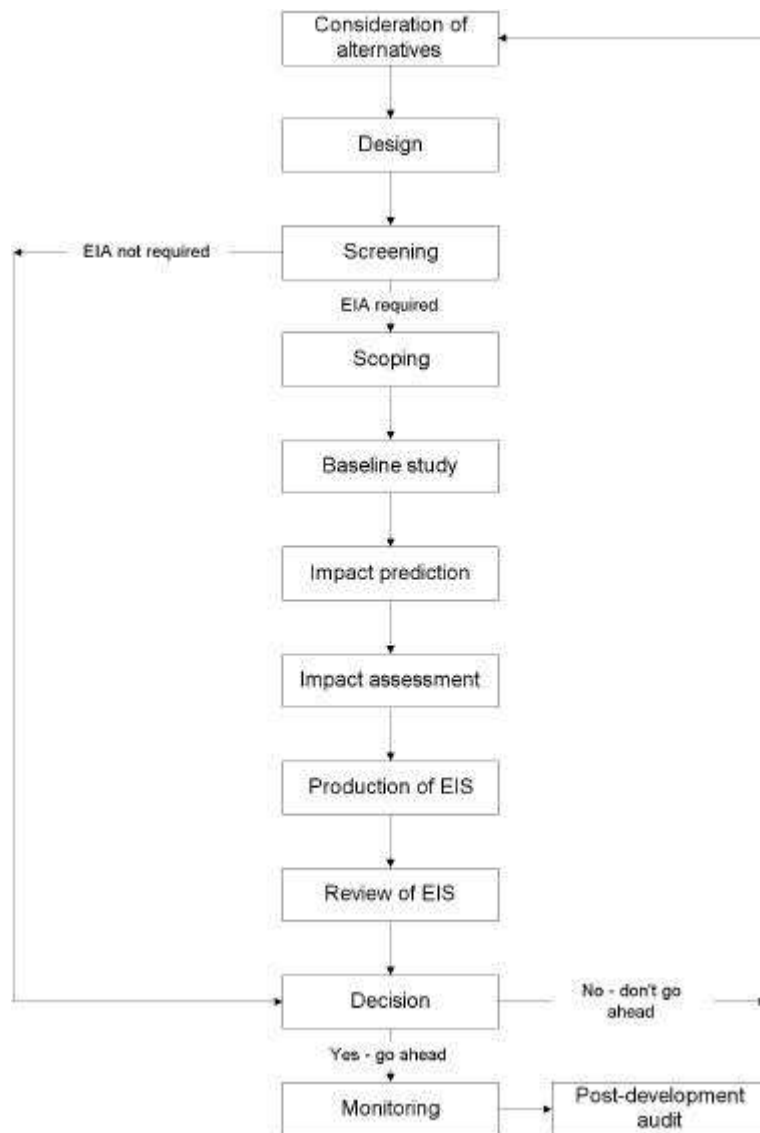


Figure 3.1: EIA process³⁹.

³⁹ Diagram after Bond (2000)

3.1.3.1 Considerations of Alternatives

The first stage is to identify means of meeting similar or identical objectives. This could include alternative processes, designs and locations. LITIEMA (2002) describe the importance of exploring alternatives:

“...they may offer significant opportunities for mitigating potentially negative effects by avoidance of such effects or through the redesign of features that would otherwise give rise to negative effects.”

3.1.3.2 Screening

The screening stage determines whether an EIA is necessary due to possible significant impacts on the environment. If the project is categorised as a Schedule 1 project then it must undergo an EIA and if it is a Schedule 2 project then further investigation is required to determine whether its impacts on the environment are significant (Hopkinson, 1997). Projects which do not fall under either of these categories do not require an EIA. Projects not required to undergo an EIA are allowed to proceed through the normal planning process without any loss of time and expense (British Medical Association, 1998).

3.1.3.3 Scoping

If the project is deemed to have a significant impact on the environment then the next stage is to define these impacts. The British Medical Association (1998) define scoping as:

“...procedures used to determine the range of issues which should be addressed in the EIA and to identify those which should be studied in detail.”

The objective of scoping is to ensure that all relevant issues are addressed in the EIA (LITIEMA, 2002). The scoping process should involve all interested parties, including decision makers, members of the public and the scientific community and it is designed to canvass their

views (Hopkinson, 1997 and Wathern, 1988).

3.1.3.4 Baseline Study

A baseline study is then performed in order to gain information on the current status of the environment likely to be affected and information on how the environment would be expected to develop without the project (IEATLI, 1995). A full year of baseline data is advantageous since seasonal effects can be recorded (Dougherty and Hall, 1995). Typical baseline information includes hydrological, atmospheric, meteorological, geological, soil, land use, landscape, geomorphological and ecological (Bond, 2000).

3.1.3.5 Impact Prediction, Assessment and Mitigation

Once the scoping stage is complete and baseline data collected, the impacts and their magnitudes can be predicted. The size of each impact should be determined as the predicted deviation from the baseline conditions, both during the construction phase and normal operating conditions. Impact prediction should also give some indication of the probability of that impact occurring (Scan-UK, 2000).

Impacts should be quantifiable if possible and any qualitative descriptions should be as fully defined as is achievable (IEATLI, 1995). Quantitative impacts are usually derived from existing models specifically designed for the purpose, although this is not always the case. One example of a quantitative technique used in the evaluation of air quality impacts is the Gaussian air dispersion model which predicts the concentration of an air pollutant from a chimney stack at a certain point in space (figure 3.2). However, many impact predictions rely on the opinion of experts, especially qualitative issues such as visual impact assessment, although there may often be scope for making such impacts more quantifiable.

Impact assessment is used to determine the importance and significance of the predicted impacts

using national and international quality standards as applicable. An impact may be large, but that does not necessarily mean that it is significant. For example, a project may have a large noise impact, but if that noise does not affect anyone then it may be deemed insignificant. This impact assessment forms a crucial part of the EIA process.

The Gaussian Dispersion Model

$$C(x, y, z, t) = \frac{Q}{2\pi u \sigma_y \sigma_z} \times \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right]$$

where

- C : pollutant concentration at point (x, y, z)
- u : wind speed (in the x “downwind” direction, m/s)
- σ_y : the standard deviation of the concentration in the x or y direction
- Q : emission rate (g/s)
- H : effective stack height (m)

Figure 3.2: The Gaussian Dispersion Model ⁴⁰.

Mitigation is the process where measures are taken to either reduce or remove identified impacts. Mitigation methods include for example, landscaping to reduce visual impacts, process redesign to reduce air, water and ground pollution and soundproofing to reduce noise impacts. The effectiveness of proposed mitigation methods should be clearly defined, as well as when and how these measures will be carried out (IEATLI, 1995).

3.1.3.6 Production of an Environmental Impact Statement

An Environmental Impact Statement (EIS) is a document describing a proposed project, a description of significant effects, alternatives to the proposal and measures to protect the environment (Gilpin, 1995 and Hopkinson, 1997). It is produced using the information gathered from the screening, scoping, baseline study, impact prediction and impact assessment and mitigation stages. These requirements of an EIS are described in more detail by Bond (2000).

⁴⁰ Equation adapted from Polytechnic (2003).

An EIS must also contain a Non-Technical Summary (NTS) that will enable non-experts to understand its findings.

One of the problems with an EIS is that it is often produced by the developers which can lead to bias. An EIS will frequently promote the good points of the project but may gloss over its bad points. One potential solution to this is to insist that the EIS should be performed by an independent authority. However, this is not a legal requirement for most of Europe with the exception of Denmark (Bond, 2000).

3.1.3.7 Review of Environmental Impact Statement

The EIS review stage involves an appraisal of the EIS by the appropriate authority that can permit or refuse the development application. The statement should be checked for consistency, omissions, bias and accuracy (Bond, 2000). There are a number of methods for reviewing an EIS, but most use some form of checklist. The European Commission (2001) have produced an EIS Review Checklist to give guidance to the various competent authorities.

The developer may be required to provide further information if the submitted information is deemed to be inadequate (European Commission, 2001). If the application is refused then new design alternatives must be produced and the EIA process started over again.

3.1.3.8 Monitoring and Auditing

Monitoring is performed in order to determine whether the impact predictions were accurate and to ensure that no unexpected effects are occurring (Bond, 2000 and British Medical Association, 1998) and involves measuring and recording physical, social and economic variables associated with the development (Scan-UK, 2000). The results of monitoring allows for problems associated with environmental impacts to be highlighted early so that action can be taken (Dougherty and Hall, 1995).

A post development audit should be carried out to compare the predicted impacts before development with the actual impacts recorded after implementation. This determines whether the predictions made in the EIA were correct, allows for feedback and aids future predictions for other development applications (Bond, 2000; Gilpin, 1995 and Scan-UK, 2000).

3.2 Leavesden Park – An Example EIA Statement

3.2.1 Introduction

In December 2001 an EIS was submitted by MEPC Leavesden Park Ltd. (Development Planning & Design Services, 2001) along with a planning application for the development of land at Leavesden Aerodrome and Leavesden Studios (hereafter referred to as Leavesden Park). Leavesden Park is located on the edge of London near Abbots Langley, with the land lying within the Metropolitan Green Belt. The application site is approximately 123 hectares (ha), with just over 19ha proposed as developed land and the remaining land proposed to be undeveloped. The site’s current main uses are shown in table 3.1, and the proposed land uses are detailed in table 3.2.

Current land use
demolished aerodrome buildings
aerodromes buildings used for film making
former runway with grassed areas, used as a backlot for filming
an open field known as the Horse Field
a partially restored landfill site called Furtherfield Landfill

Table 3.1: Current land use for Leavesden Park.

The proposals for the development of Leavesden Park are shown in figure 3.3 and are described in the NTS as follows (Development Planning & Design Services, 2001):

“The demolition of buildings and redevelopment as a technology, media and telecommunications park (Class B1) and film studio, nature reserve, open space and

recreation land together with amenity and ancillary buildings, road works including alterations to the spline road at its junction with the A41, new roads, footpaths, cycleways and car parking at Leavesden Park.”

Developed Land		Undeveloped Land	
Land Use	Area (ha)	Land Use	Area (ha)
buildings	6.61	parkland	72.26
formal landscape parking	7.55	playing fields	6.43
new roads	2.60	nature reserve	4.87
existing roads	2.39	backlot for filming	17.29
		farmland	1.16
		soft landscaping	1.79
Total	19.15	Total	103.8

Table 3.2: Proposed land use for Leavesden Park.

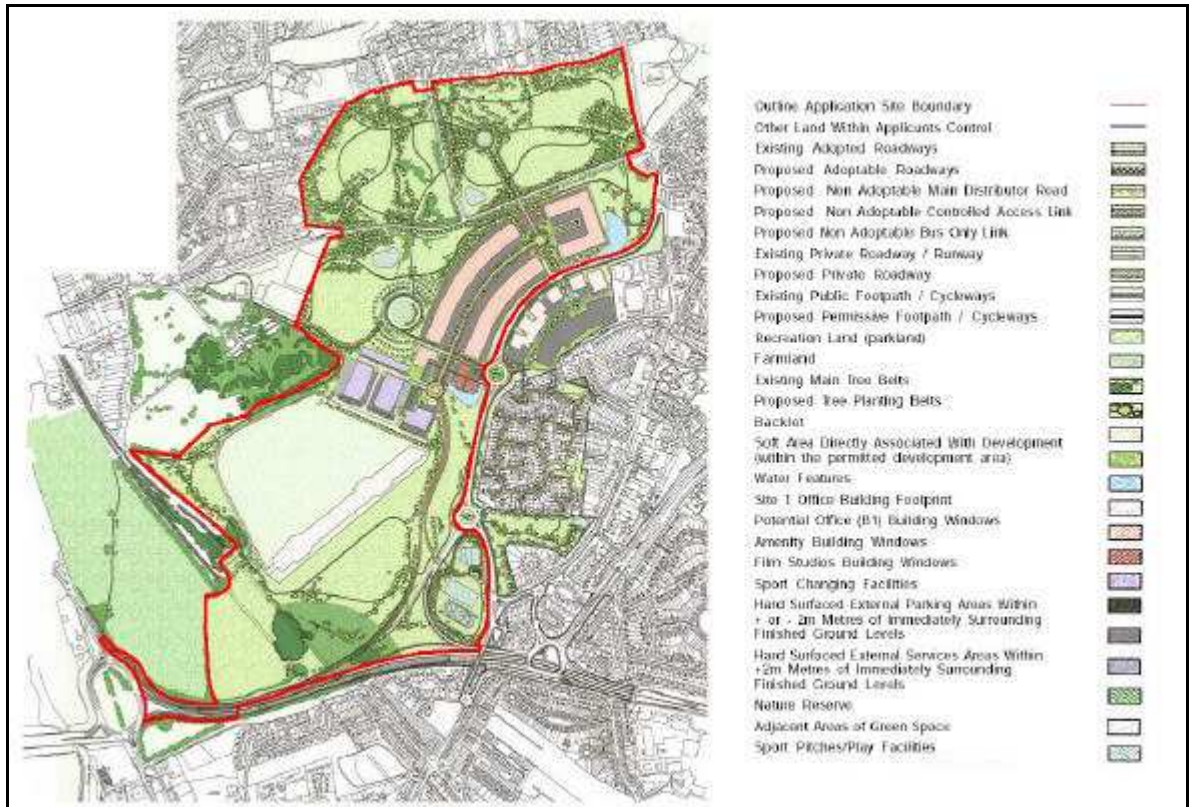


Figure 3.3: Proposals for Leavesden Park⁴¹.

⁴¹ Development Planning & Design Services (2001).

3.2.2 Environmental Issues

Assessment of the environmental issues were evaluated using methods including desk-based research, consultations and field surveys. A baseline study was carried out and compared with the potential impacts resulting from the construction period, during operation and a non-development scenario.

In total, eleven environmental issue groups were identified in the scoping stage of the EIA, including landscape and visual, noise and vibration, transportation and air quality. Each issue was assessed in detail and included baseline conditions of the site and its surroundings, relevant details from the proposals for the site, mitigation measures and the predicted impacts during construction, during operation and also the predicted impacts in the long term. Alternatives were also considered as part of the EIA and included in the EIS.

The predicted impacts were assessed on their significance to the environment using certain criteria, primarily the geographical extent of the predicted effect and the ability to mitigate or improve it. A scale was developed ranging from 'severe adverse' down to 'maximum benefit'. The significance of the effects were assessed for each of the three key periods; during construction, operation and long term.

3.2.3 Conclusion of EIA for Leavesden Park

The EIA established that the proposed development would give rise to more significant advantages than disadvantages to the environment and local community especially during operation and in the long term. The NTS summarises the long term implications of the development as (Development Planning & Design Services, 2001):

“...wholly beneficial. They would include both the maintenance and prospects for enhancement of economic prospects for the area, and a continuing increase in and development of landscape quality, species diversity and community involvement.”

3.3 Visual Impact Assessment

3.3.1 Introduction

Assessing the change in visual appearance of the landscape is often known as VIA and it is recognised, unlike many other aspects of EIAs, that it relies less upon measurement than upon experience and judgement (IEATLI, 1995).

VIA is the appraisal of the likely visual impact of man made developments upon surrounding areas, and in many cases may become a key issue capable of influencing the EIA decision making process. Pullar and Tidey (2001) define VIA as:

“...the formal process used to evaluate the visual merits of a proposed development with respect to passive human interaction.”

Visual impacts can be defined as the changes in appearance of the landscape as a result of developments and they can be either positive (improvement) or negative (detraction), direct or indirect, temporary or permanent, single or cumulative and can vary in magnitude and significance (IEATLI, 1995).

The distinction between direct and indirect visual impacts are described by LITIEMA (2002):

“A direct (or primary) effect may be defined as an affect that is directly attributable to a defined element or characteristic of the proposed development, for example, the loss or removal of an element or feature such as a hedgerow or a prominent group of trees.

An indirect (or secondary) effect is an effect that is not a direct result of the proposed development but is often produced away from the site of the development or as a result of a complex pathway or secondary association.”

Virtually all developments will generate a degree of visual impact, and questions which VIA

aims to address include where the development can be seen from and who will see it, how much can be seen, what will it look like and whether it blends into the landscape.

Unlike less obvious environmental impacts, such as groundwater pollution, changes in the visual character of the landscape have an immediate visible effect and hence provoke strong feelings from the public. This can also be used as a focal point for other concerns about the impact of a development (IEATLI, 1995). Therefore accurate predictions of the visual impact of a development can play an important role in an EIA.

For many categories of environmental impacts such as noise, air and water quality, levels of magnitude will be based on established, measurable technical thresholds and the sensitivity of receptors (the entities that will experience an effect) may also be defined in statutory regulations or planning guidance. LITIEMA (2002) states:

“No such formal guidance exists for the assessment of significance for landscape and visual effects and the assessor must clearly define the criteria used in the assessment for each project, using his or her skill based on professional judgement.”

Figure 3.4 (modified from Lange, 1994) shows examples of qualitative and quantitative standards for various environmental disciplines. Zewe and Koglin (1995) state:

“There are nearly no quantitative techniques for the evaluation of visibility.”

Pullar and Tidey (2001) agree by stating:

“Currently there are only a few methodologies that include visual impacts in any quantitative way in the design process.”

Visual impact is mostly assessed qualitatively since it is concerned with the human appreciation of the landscape (Wherrett, 2002). Lange (1994) states that:

“A major reason for the subjectivity inherent in the evaluation process is that aesthetic

rules for the environment exist only to a certain degree, i.e. individually there is a great variation in the visual landscape, based on different individual experiences, social level and cultural background.”

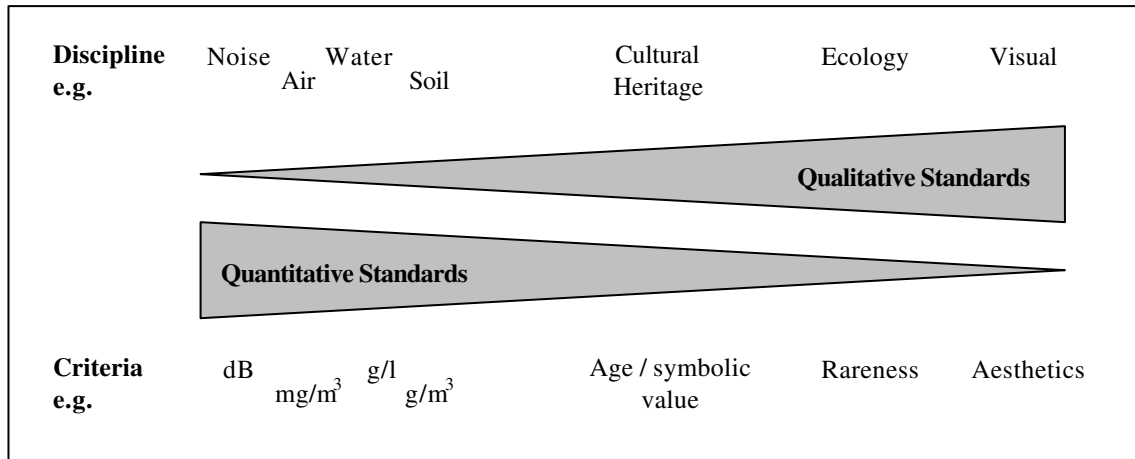


Figure 3.4: Examples of qualitative and quantitative standards⁴².

The main problem with qualitative techniques in assessing visual impact is that they may lead to bias due to their inherent subjectivity, hence there is a need for a more structured and consistent approach towards VIA.

3.3.2 Legislation

Since VIA is an important part of the EIA process, its application is governed by the EC Directives 85/337/EEC and 97/11/EC which have been discussed earlier. However, in 1995 and subsequently 2002, LITIEMA (formerly known as IEATLI) published guidelines for VIA which have provided a benchmark which is used in many assessments.

In the UK, visual impacts have been a part of development control for eighty years and they became national in scope in 1947 with the publication of the Town and Country Act and the National Parks and Access to the Countryside Act of 1949 (Wherrett, 2002).

⁴² Image by the author (July 2002) adapted from Lange (1994).

3.3.3 The Visual Impact Assessment Process

The VIA process is somewhat comparable in its stages to the overall EIA process described earlier in this chapter. The following brief description provides an overview of the VIA process as suggested by IEATLI (1995) and LITIEMA (2002).

3.3.3.1 Description of the Development and Considerations of Alternatives

The description of the development must include a description of the site, layout and essential characteristics of the development within its landscape context. LITIEMA (2002) stress that the description of the development is very importance since:

“...it is the foundation for all prediction of effects. It also assists the overall design process and leads to the best and most sustainable environmental solution.”

Alternatives should also be explored and can include different locations, size and scale of development, site layouts, scheme design and processes. The ‘do nothing’ situation should also be considered against which the development will be compared (IEATLI, 1995 and LITIEMA, 2002).

The main benefit of exploring alternatives is described by LITIEMA (2002):

“...they may offer significant opportunities for mitigating potentially negative affects by avoidance of such effects or through the redesign of features that would otherwise give rise to negative effects.”

3.3.3.2 Baseline Studies

The existing visual resource should be described, classified and evaluated, particularly with respect to its sensitivity and ability to accommodate change (IEATLI, 1995). This data will form the basis against which to review the predicted visual impacts of the proposed

development.

The baseline study may delineate the areas likely to be directly affected by the proposed development, identifying the principal viewpoints and drawing attention to sensitive receptors. Visual receptors include the public or community at large, residents, visitors, and other groups of viewers as well as the visual amenity of people affected (LITIEMA, 2002).

The actual extent of visibility will need to be checked in the field due to localised screening effects from buildings, walls, fences, trees, hedgerows and banks for example (IEATLI, 1995 and LITIEMA, 2002).

Not only do baseline studies play an important part in the assessment process but also in the design process as LITIEMA (2002) states:

“...provides an overview of the environmental constraints or opportunities that may influence the design of the final development.”

3.3.3.3 Potential Impacts, Magnitude and Significance

The most important stage of a VIA is the identification of potential impacts, prediction of their magnitude and the assessment of their significance. It is important to consider the potential impacts of a proposed development at different stages in its life-cycle. For example, impacts during construction should be evaluated separately from operational impacts of the final design (IEATLI, 1995).

The main requirements in predicting visual impacts as described by IEATLI (1995) and LITIEMA (2002) are:

- ?? the extent of potential visibility,
- ?? the views and viewers affected,
- ?? the degree of visual intrusion or obstruction that will occur,

- ?? the distance of view,
- ?? the resultant impacts upon the quality of views,
- ?? whether the view is transient or one of a sequence of views, as from a moving vehicle or footpath,
- ?? the timing and duration of impacts.

Consideration should be given to seasonal variation which will affect the amount of vegetative screening throughout the year, and hence a worst case scenario of winter views should also be considered.

The sensitivity of visual receptors and view depends upon the location and context of the viewpoint, the expectations and occupation or activity of the receptor, the importance of the view, which mainly depends upon the number of people affected, and the length of time the receptors view the scene (Bergen, 1993). Figure 3.5 shows the sensitivity of common receptors as expressed by IEATLI (1995) and LITIEMA (2002).

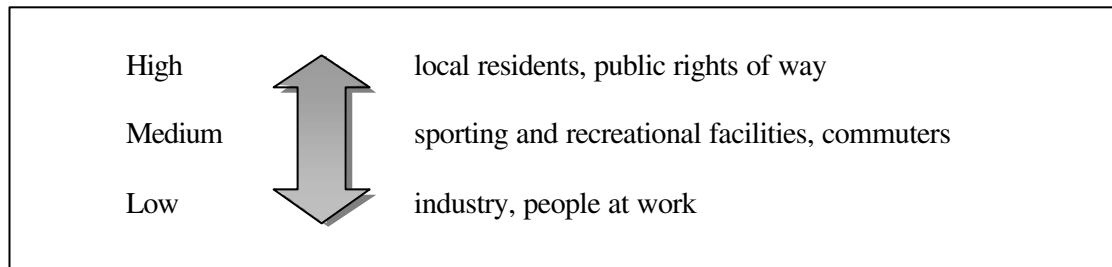


Figure 3.5: Sensitivity of some common visual receptors⁴³.

The magnitude of visual effects can be determined by a number of factors. LITEMA (2002) list these as:

- ?? the scale of change in the view,
- ?? the degree of contrast of any new changes in the landscape,
- ?? the duration and nature of the effect, for example, temporary or permanent, intermittent or continuous,
- ?? the angle of view to the receptor,

⁴³ Image by the author (July 2002) adapted from IEATLI (1995) and LITIEMA (2002).

- ?? the distance between development and receptor,
- ?? the extent of the area within which the changes would be visible.

The significance of a visual impact is determined by the magnitude of the impact and the sensitivity of the receptors. Therefore significant impacts occur when high magnitude effects occur on highly sensitive receptors. However, a higher level of significance is attached to sensitivity than on magnitude, hence a small effect on a highly sensitive receptor is often more important than large effects on less sensitive receptors (LITIEMA, 2002).

3.3.3.4 Mitigation

For mitigation measures to become successful they must be effective, appropriate and feasible. They must also be designed to suit the existing landscape character. Impacts should be mitigated throughout the project life-cycle and it should be recognised that some measures will not be immediately effective, such as vegetative screening (IEATLI, 1995).

Mitigation strategies include avoidance, reduction, remediation and compensation. Of these, avoidance is the most desirable and can be achieved through careful siting, planning and design. Where negative visual effects cannot be avoided then effects should be reduced by detailed consideration of site characteristics. For example, a development could be set into the ground to reduce its visual extent on the landscape. Remediation measures include those which rely on added features to screen the development from sensitive receptors, such as vegetative planting which were not part of the initial development design (IEATLI, 1995 and LITIEMA, 2002).

As a last resort, compensatory measures can be used to compensate for any unavoidable visual effects. Such measures include off-site planting carried out for affected receptors, or the provision of a new local amenity area or park (LITIEMA, 2002).

Environmental enhancements, such as improved land management, restoration of historical

landscapes, habitats and other valued features, should also be considered (IEATLI, 1995 and LITIEMA, 2002).

3.3.3.5 Presentation of Findings

Plain language, a clear structure and good illustrative material should be used for the presentation of findings. A concise NTS is also required as an aid to communication. Value for money, simplicity, accuracy and suitability should be considered in the choice of presentation techniques (IEATLI, 1995). Methods for presenting findings from VIAs are described later in the chapter.

3.3.3.6 Consultation, Review and Implementation

There are various forms of consultation which fulfil many purposes at different stages in the VIA process. Consultations can involve regulatory authorities, statutory consultees, amenity and conservation bodies and local residents (IEATLI, 1995). LITIEMA (2002) state:

“Consultation is an essential part of the landscape and visual impact assessment process, whether for the purpose of gathering specific information about the site, or for canvassing the views of the public on the proposed development. It can be a valuable tool in seeking understanding and agreement about key issues and can highlight local interests and values, which may otherwise be overlooked. With commitment and engagement in a genuinely open and responsive process, consultation can also make a real contribution to scheme design.”

Adequacy of a VIA is determined by the regulatory authority. A review process will check that the assessment meets the requirements of the EIA regulations and also the specific terms of reference discussed and agreed with the developer. The review will consider the scope and content of baseline studies, the methodology and techniques applied, accuracy and completeness of identification and evaluation of potential effects, the criteria and thresholds used to assess the

predicted effects, and the effectiveness of proposed mitigation (LITIEMA, 2002).

Once a development consent is granted, the developer and the regulatory authority have a responsibility to ensure that commitments made in the application and EIS are honoured throughout all stages of the project life-cycle. Implementation is usually achieved through the enforcement of consent conditions, legal agreements, undertakings or other requirements (IEATLI, 1995 and LITIEMA, 2002).

Long term management and monitoring of mitigation measures may be required and IEATLI (1995) and LITIEMA (2002) list a number of purposes for monitoring:

- ?? establishing whether or not predicted impacts actually occurred,
- ?? identifying unforeseen impacts and omissions from the original EIS and ensuring an appropriate response,
- ?? checking compliance with proposed mitigation measures and planning conditions,
- ?? checking the effectiveness of mitigation measures in avoiding or reducing adverse impacts.

The process of VIA has been briefly summarised from the initial description of the proposed development through to implementation and monitoring. With all VIAs, the identification of potential visual impacts is of most importance. This stage in a VIA relies heavily upon accurate identification and measurement techniques and some of these are described below.

3.3.4 Current Visual Impact Assessment Techniques

A wide range of methods have been developed and implemented as tools for impact assessment, both computerised and non-computerised. Some methods aim to systematically identify the potential landscape and visual impacts of the development, whilst others aim to predict and estimate the magnitude of the visual impacts.

Fels (1992) believed that there are three types of issues that VIA addresses; spatial, quantitative

and qualitative. Spatial issues determine where the development is visible from. One technique for determining spatial visual impact is a FVI. Quantitative issues are concerned with how much of the development can be seen, how much area is affected and to what degree. Quantitative methods used to assess visual impact include solid angle calculations and landscape evaluation. Qualitative issues involve the visual character of the development and its compatibility with its surroundings. Examples include computer generated animations, perspective views and descriptive statements

Table 3.3 shows the main methods for VIA and lists whether they are manual techniques or involve the use of computers, or whether the methods can be employed by both. A further description of some of the methods is given below.

Technique	Spatial	Quantitative	Qualitative	Manual	Computerised
FVI	?			?	?
Helium balloon	?			?	
Percentage view change		?		?	?
Solid angle		?		?	?
Vertical angle		?		?	?
Landscape evaluation		?		?	?
Number of targets seen		?		?	?
Descriptive statement			?	?	
Identification checklist and matrix			?	?	
Scaled model			?	?	?
Perspective views			?	?	?
Photomontage			?	?	?
Animated fly-through			?		?
Virtual reality (VR)			?		?

Table 3.3: Methods of VIA.

3.3.4.1 Fields of Visual Influence

An FVI (also known as an intervisibility map, viewshed or zone of visual intrusion) delineates the area around a proposed development from where the project will be visible. FVIs are an important element of VIA since they can be used as a precursor to the selection of individual views for more detailed assessment (Wood, 2000).

An FVI is normally represented by a 2D map, with shaded areas representing areas that are visible. The map can be combined with various media to improve the visualisation of the data which is especially helpful for presentations to the public to help them make sense of information presented to them. Such mediums include layout drawings from software such as AutoCAD, OS maps and aerial photographs. An FVI can also be presented in 3D by draping the FVI over a 3D computer generated terrain model.

FVIs can take a number of forms, including projective and reflective, individual and composite (also known as cumulative). Projective FVIs are initiated from viewpoints within the development and delineate the extent of visibility of the development to its surroundings. Reflective FVIs are initiated from viewpoints in the surrounding area and determine whether, and to what extent, the development is visible (Fels, 1992).

Individual FVIs are used to evaluate the effects of a specific component of the development or to determine the extent of visibility of a development from a single location. Fels (1992) states that composite FVIs:

“...portray the visibility of every point in the development with respect to every point in the landscape. If the object of study is a form of development, such as a landfill or an electrical transmission line, the study must include every model point within that landfill or along that transmission line...These maps are the most effective means for producing comprehensive appraisals of spatial and quantitative impact issues.”

One traditional method, first developed in the early 1970s, for creating FVIs involves plotting topographic sections and sight lines at 10° intervals (Wood, 2000). This method is still used today, often with the assistance of computers and DTMs. However, this radial line method is inherently problematic because of the increasing distance between the radials (KeyTERRA-FIRMA Ltd., 2002). To overcome this problem, further radial lines are created as the distance from the centre increases (figure 3.6).

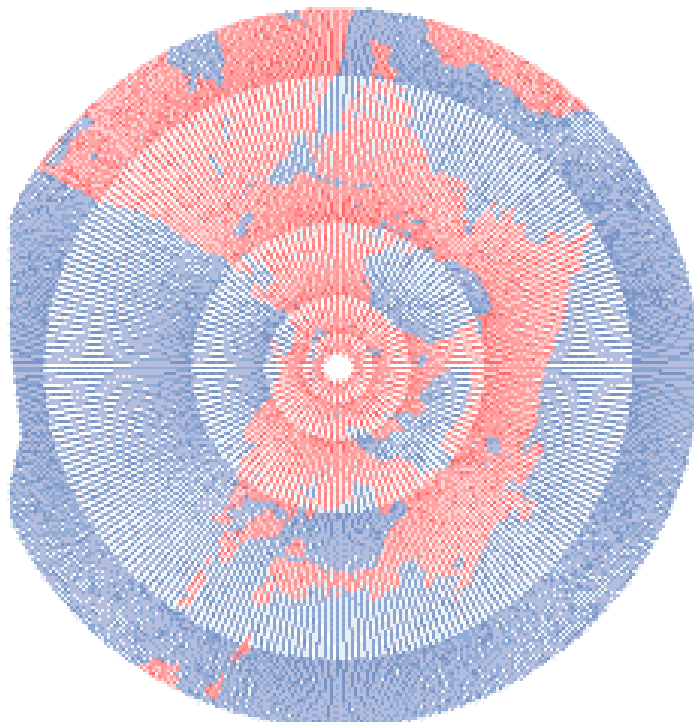


Figure 3.6: A radial line FVI with red areas indicating visibility⁴⁴.

Other older FVI techniques use algorithms which have been developed for automatic viewshed computations using DEMs. Examples include Travis *et al.* (1975), Floriani *et al.* (1986), Goodchild and Lee (1989), Fisher (1991), Sorenson and David (1993) and Sansoni (1996). Sansoni's visibility test algorithm, one of the more recent algorithms, took into account the Earth's curvature and refraction and also simple buildings and vegetation. However, these type of viewshed algorithms are computationally intensive and hence time consuming (Wang *et al.*,

⁴⁴ Image from KeyTERRA-FIRMA Ltd. (2002).

1996) and accuracy is dependent upon the size of the DEM grid interval (a smaller grid size yields more accurate results).

Early FVI computer software included VIEWIT (Travis *et al.*, 1975), SIGHTLINE (Nickerson, 1979) and DTS (Young and Lemkow, 1976). Today, many GIS software packages have some sort of FVI function, one popular example being ESRI's ArcInfo (Bergen, 1993; Fisher, 1996 and ESRI, 2002). However, the FVI features of many of these GIS software packages do not take into account surface features such as buildings and vegetation, or natural features such as vegetation growth, seasonal variations, atmospheric effects, or Earth curvature and refraction. Those GIS packages that do are often crude and surface features are simplified to simple shapes or solid blocks of vegetation.

McCarthy Taylor Systems Ltd. (2002) have developed a product called LSS Elite which includes a feature for overlaying its FVIs with boxes representing the number of visible targets (figure 3.7). This is very useful for developments such as wind farms where the number of wind turbines plays an important role in assessing the visual impact. This could be taken further by shading the FVI to represent the percentage of view of the development. Other software packages capable of producing FVIs include 3D Studio VIZ Release 3 (Autodesk Inc., 2002a), SCCW (Atlas Computers Ltd., 2000), and Horizons (Berney, 2000).

The accuracy of any FVI technique is directly associated with the accuracy of the landscape model used in the FVI derivation. As part of his research, Fisher (1993) explored several alternatives for inferring elevations from a basic DEM. The study found that FVIs that were produced using the various alternatives varied considerably. Following on from this study, Fisher (1994) suggested the use of a probable viewshed, which is defined as the summation of FVIs obtained from different versions of a DEM.

Some limited research has been carried out by Felleman (1982) and more recently by Wood

(2000) to compare different FVI methods and their accuracy. Felleman (1982) evaluated FVIs produced on the basis of field observation, topographic maps, physical topographic models and computerised DTMs and found that each of the different methods tested produced different FVIs and that the sensitivity analysis produced areas of ambiguity.

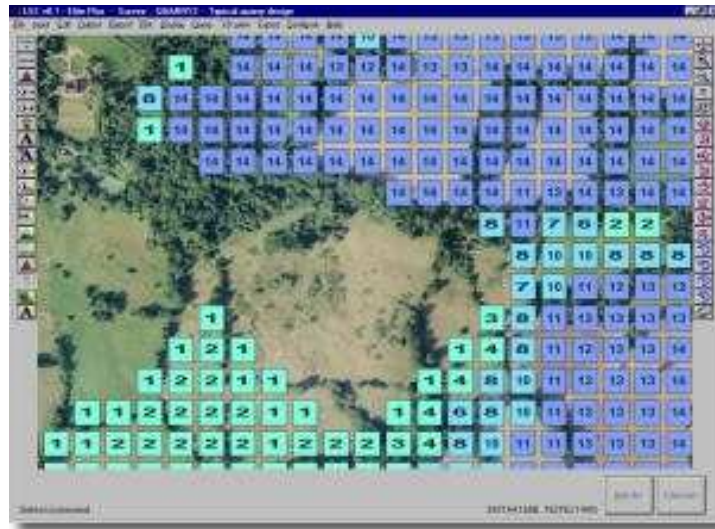


Figure 3.7: An FVI with boxes representing the number of visible targets⁴⁵.

Wood (2000) went further by testing various FVI predictions for their accuracy to identify the extent of impact over-prediction, under-prediction and the occurrence of no-error. Wood (2000) does not present a preferred FVI method but does state:

“...it appears that the failure to adequately consider the effects of physical barriers to visibility (e.g., buildings and vegetation) served to explain the pattern of errors identified.”

3.3.4.2 Helium Balloons

Helium balloons, most typically weather balloons, are a traditional technique used for determining where proposed developments can be seen from. This is especially the case for tall and thin buildings such as chimney stacks. The balloon is deployed at the position of the

⁴⁵ Image from McCarthy Taylor Systems Ltd. (2002).

proposed development and floated to the development height. Field work is then carried out by photographing the balloon from various critical viewpoints to see whether it is visible or not.

The method is very simple, and hence cheap and quick to perform. The main disadvantages of this method is its limited coverage, hence it is not very useful for visualising large scale or complex developments, and it is weather dependent. It is also neither qualitative nor quantitative and hence this method cannot give an indication of how the development will look nor will it give a good indication of how much the visual receptors will be affected.

3.3.4.3 Percentage View Changes

Percentage view change is a technique that has not been used to its full potential in VIAs. The technique is currently often used to manually estimate the change a development will have on its surroundings, for example percentage of views are determined by placing a grid over a picture and manually counting the number of cells that contain the attribute of interest (Meitner and Daniel, 1997).

Brush and Shafer (1975) used a transparent quarter inch grid to calculate the area of certain landscape features from photographs in order to determine landscape preference scores which could be used by decision makers in the VIA process. The accuracy of this method was dependent upon the size of the grid cells, with smaller grid cells increasing the accuracy but also increasing the time taken to calculate the area of interest.

A traditional manual method for calculating non-uniform areas uses a drafting implement called the planimeter. The method involves tracing around the regions whose area is to be determined and the planimeter automatically calculates and displays the area. However, this method is prone to human error and it can be extremely difficult to determine the area of multiple, small, complex shapes and hence it can be time consuming.

LandCalc (Aldex Software Ltd., 1999) is a software package which is essentially a computerised version of a planimeter. Using a mouse or other input device, the user traces round the regions in question and the software automatically calculates the area of the traced regions. This method features the same drawbacks as the manual planimeter method.

Many graphic software packages, such as Adobe Photoshop 5.0, have the facility to accurately calculate a particular area of an image, usually in the form of the number of pixels. This is accomplished by individually selecting the required areas, usually by using colour selection tools. However, problems arise with complex images such as landscape scenes, where it is hard to select individual features for pixel counting since the features overlap and interact with other features of similar colour, such as vegetation. One method by which this problem can be overcome is by colouring the feature of interest with a single unique colour which can then be easily selected by the software package. However, this method can be very time consuming depending upon the complexity of the image, and accuracy problems can again easily arise due to human error.

As with the FVI techniques, the results obtained from a percentage view analysis technique rely upon the accuracy of the 3D CG model used. Using a technique similar to Fisher's (1994), a probable percentage view change analysis can be performed by averaging the results from several assessments that have been based upon DEMs with different error fields.

Although it is possible to quantitatively determine the percentage change in view due to a proposed development, the size of this change that constitutes an acceptable or unacceptable impact is still unknown. Stamps (1992), Watzek and Ellsworth (1994) and Lange (2001) performed studies that assessed how participants responded to sets of real and simulated landscape and urban images in order to determine the importance of realism. Stamps (1992) determined how well photomontages simulated real environments by asking a number of respondents to identify which parts of twelve photographs of urban scenes had been simulated.

The study determined that less than fourteen percent of the responses were correct identifications. Watzek and Ellsworth (1994) performed a similar study, in which respondents were asked to evaluate the accuracy of various images that were scale altered using CG techniques. The study showed that the respondents were not able to recognise differences between images that had been scaled up and down by fifteen percent. More recently, Lange (2001) performed an empirical study that tested the validity of a virtual landscape by asking a number of respondents to order a set of real images and various rendered images of the virtual landscape images. In the experiment, approximately seventy-five percent of the respondents assigned a very high degree of realism to one or more of the simulated landscape images.

These studies show that it may be possible, by showing numerous sets of pre and post development images to a number of respondents, to determine the approximate percentage view change values that constitute acceptable and unacceptable changes in view due to a proposed development. For example, it could be determined that a four percent decrease in vegetation is the cut off value between an acceptable and unacceptable visual impact.

The image processing tools described above which calculate particular areas of an image are not widely used and tools specifically designed to efficiently calculate the percentage change in views do not currently exist for VIAs.

3.3.4.4 Solid Angles and Vertical Fields of View

In mathematical terms, a solid angle of 1 steradian is the angle subtended at the centre of a sphere by an area on its surface numerically equal to the square of the radius (Mischler, 2002). Figure 3.8 shows the calculation of a solid angle, the basic unit being a steradian (sr) which is strictly unitless.

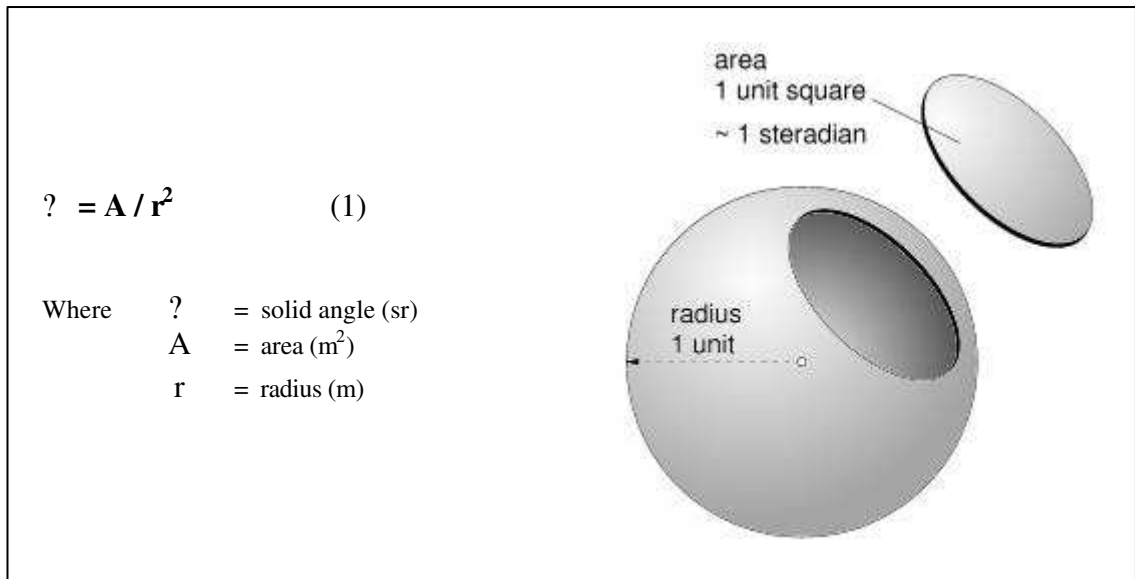


Figure 3.8: A solid angle⁴⁶.

Zewe and Koglin (1995) state that a solid angle is “...a measurement for the apparent size of an object”. They used solid angle calculations as part of a computerised method to determine the visual impact of objects on the landscape, namely electricity pylons. However, to calculate the area of a pylon they scan converted (digitising an image using a scanner) the pylon image into a matrix with a resolution of only twenty five by thirty and counted the number of pixels covered by the pylon. Inaccuracies are high with such a low matrix resolution but this resolution was necessary in order to keep processing time down to an acceptable level.

The main advantage of using solid angle calculations in VIAs is that a measure of how much of a given field of view is occupied can be calculated automatically taking into account the effect of distance. The main drawback with the solid angle method is that determining the visible area of an object is a very difficult task, and is made harder when the object is a complicated shape and masked by other complex objects such as trees.

The vertical field of view (vertical angle) method is one whereby the visual impact is linked to the vertical angle subtended at the viewpoint by the top and bottom extremities of the object

⁴⁶ Image modified from an original by Mischler (2002).

being viewed (McCarthy Taylor Systems Ltd., 2002). This gives a measure of how much of the vertical field of view the new development will occupy. This method is very crude but is simple to determine and is quantifiable.

McCarthy Taylor Systems Ltd.'s LSS Elite software package has a vertical field of view function which allows the visible vertical angle of an object to be determined. Numerous vertical angle calculations can then be displayed as contours which aid in the quantification of intrusion across large and small areas alike (McCarthy Taylor Systems Ltd., 2002).

3.3.4.5 Landscape Evaluation

Landscape evaluation is a method which tries to evaluate the aesthetic value of a landscape. There are numerous models which have been developed in an attempt to successfully achieve this using both qualitative and quantitative procedures.

Wherrett (1998) subdivided the numerous models into three categories; descriptive inventories, public preference methods and quantitative holistic techniques. Wherrett (1998) describes the different categories as follows:

“Descriptive inventories include ecological and formal aesthetic models, methods which are mostly applied by experts in an objective manner. Public preference models, such as psychological and phenomenological, are often undertaken using questionnaires, and are unavoidably linked to the problems of consensus among the public. Quantitative holistic techniques use a mixture of subjective and objective methods and include psychophysical and surrogate component models.”

Wherrett (1998) goes on to summarise the different approaches:

“Descriptive inventories include methods based on the overall similarity of landscape units, and methods which identify relationships between landscape components and

environmental quality. Several such methods are described in Daniel and Vining (1983).

Public preference methods most commonly use questionnaires or verbal surveys to sample the scenic preference of the general public. Psychological and phenomenological models are also used, both, however, are more subjective than objective.

Quantitative holistic techniques, which combine the approaches of public preference surveys with landscape feature inventories, measure landscape 'quality' as related to the physical, biological and social features of the landscape (Arthur et al, 1977). The models tend to predict scenic preference rather than try to classify landscapes or to explain preference (Buhyoff et al, 1994)."

Examples of the various methods include the model devised by Shafer *et al.* (1969), the Visual Management System (VMS) model (UDSA Forest Service, 1973), the Scenic Beauty Estimation (SBE) model (Daniel and Boster, 1976), and Meitner and Daniel's GIS approach (Meitner and Daniel, 1997).

Problems and errors occur in all the different types of models, these errors include mathematical and philosophical errors. Another drawback to landscape evaluation models is that they are mostly designed for rural scenes and hence may not give reliable results for urban scenes. However, the largest problem with landscape evaluation models is that although they can produce quantitative results, many of the models are based upon subjective input such as questionnaires and surveys.

3.3.4.6 Number of Targets Seen, Descriptive Statements, Checklists and Matrices

The number of targets seen method is a quantitative technique in which visual impact is linked to the number of visible targets of a development. This technique has been described earlier in section 3.3.4.1 using the software package LSS Elite as an example.

Descriptive statements give factual descriptions of the before and after scenarios of a proposed development. These statements are widely used and if used correctly can form the basis of a VIA if other methods are also used. Although they can be highly subjective, they are simple to produce and cost effective.

Checklists and matrices can be used in a variety of ways including the systematic comparison of sources of impact or the magnitude of impact with visual receptors. They can present a large amount of information in a concise form (IEATLI, 1995), and although they are mainly used qualitatively, checklists and matrices can be used quantitatively if combined with other quantitative methods such as percentage view changes.

3.3.4.7 Physical Scaled Model

Physical models, such as the one shown in figure 3.9, are good tools for helping to visualise a proposed development and are often used in presentations for major developments. Physical models, which require skilled labour, are time consuming and expensive to build and are therefore not very good for visualising multiple planning alternatives, or adapting to changes in design.

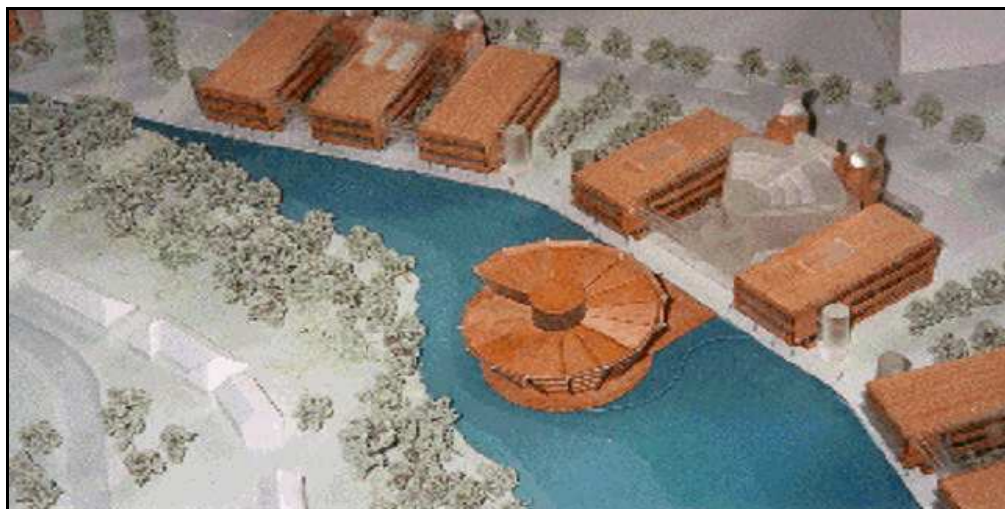


Figure 3.9: A physical scaled model of the Jubilee campus, Nottingham⁴⁷.

⁴⁷ Photograph taken by the author (May 1999).

Accuracy is another disadvantage, for example, a one millimetre error in a model at a one to five thousand scale would lead to a five metre error when scaled up. Although physical models can be a useful visualisation and design tool, the visual impact of the development cannot be quantitatively assessed.

3.3.4.8 Perspective Views

Perspective views of a proposed development can be produced in a number of ways including paintings, sketches or computer simulation. Paintings and sketches of a development have the advantage that they can be produced on site, but can be subject to bias from the artist and can be time consuming to create. This is especially true if the design of the development changes or multiple views are required.

Computer simulations have the advantage that once the 3D model has been built it can offer many more viewpoints than manual techniques and design changes can be implemented quickly to the 3D model. Computer simulations can also produce views quickly at various times of the day and in different seasons by changing lighting conditions and varying vegetative textures for example. Figure 3.10, created by TJP Envision Ltd. (2001), shows a computerised perspective view of proposed woodland planting which would have been difficult to produce using non-computerised methods due to the elevated viewing location and detailed terrain.

For computer simulations to be useful for VIA they must be as accurate and photo-realistic as possible and Nakamae *et al.* (2001) state:

“In order to create photo-realistic landscape images, attention to the spectral characteristics of reflection, refraction, and transparency of objects (such as artificial objects and water surface), and the modelling of natural objects (such as trees) are also indispensable.”

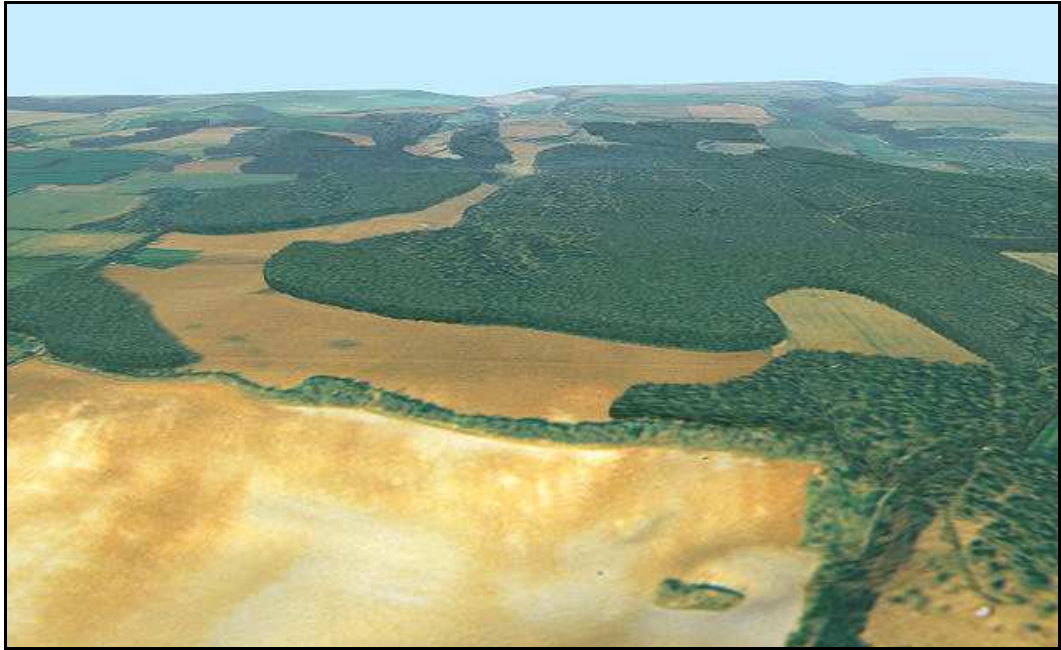


Figure 3.10: Computer simulated perspective view of proposed woodland planting⁴⁸.

The choice of lenses for the virtual cameras used to create the views in the 3D computer models is very important as IEATLI (1995) explains:

“Wide angle lenses reduce the apparent height of landform, buildings and vegetation; while telephoto lenses tend to increase it. Accepted practice is to use a lens with a focal length of between 50 and 65mm; there are inherent dangers in using other lenses by misrepresenting impacts through reduction or enlargement.”

Producing photo-realistic images can involve a great deal of modelling time and computer processing power which can lead to high costs. Another drawback with using perspective views, both computerised and manual, for VIA is that the views are often determined by the developers and hence they may not show the development in the worst case scenario.

⁴⁸ Image from TJP Envision Ltd. (2001).

3.3.4.9 Photomontages

IEATLI (1995) define a photomontage as:

“...the superimposition of an image onto a photograph for the purpose of creating a realistic representation of proposed or potential changes to a view.”

Before the use of computers, photomontages were usually created by manually painting the details of a development, often in oils or gouache (LITIEMA, 2002), onto a photograph and then re-photographing the finished product (figure 3.11). This method was slow and tedious, and Wherrett (2002) states:

“Fortunately, the limitations of manual photomontage techniques have largely been resolved, using computer simulation techniques. As a result, digital photomontages are now commonly used in viewpoint analysis in the VIA process.”



Figure 3.11: Hand painted photomontage⁴⁹.

⁴⁹ Image from IEATLI (1995).

The more common approach nowadays is to scan a base photograph into a computer and, using a graphics package, overlay the proposed development image over the photograph image. There are two main ways to produce a technically accurate development image which matches the background photograph.

The first method is to record the exact location, bearing, pitch and focal length of the camera where the photograph was taken. The camera is then recreated in the new development 3D model and the view rendered. This method is prone to human error since it is not easy to measure the aforementioned camera details accurately.

The second method is to model the new development including some of the surrounding landscape and prominent surface features, such as buildings, which appear in the photograph. Using the photograph as a background image, a camera can be created which view matches the background photograph. Some 3D graphic software packages such as Discreet's 3D Studio MAX range (Autodesk Inc., 2002b) (see appendix 1) have functions for automatically matching camera views using known points in the 3D model and points on the background photograph. This method relies upon an accurate 3D model and is therefore also time consuming.

To produce photo-realistic photomontages environmental conditions must be considered when creating the 3D model. Environmental conditions include direct and indirect (reflected) light, shadows, weather conditions (fog for example), earth curvature and atmospheric refraction. As with perspective views, a focal length of between 50 and 65mm should be used to give an accurate representation of the view (IEATLI, 1995).

Figure 3.12 shows a photomontage also produced by TJP Envision Ltd. (2001) of a combined-cycle gas turbine power station. The power station, situated in the background, has had a fog effect applied to it, amongst other environmental effects, in order for it to fit in with the background of the photograph.

The main advantages of using photomontages is that they show the development within the real landscape and from known viewpoints (IEATLI, 1995). Sparkes and Kidner (1996) briefly describe the advantages and disadvantages of photomontages:

“Because the public are used to looking at photographs, the image is quickly understood and leaves little room for misinterpretation. Unfortunately photomontages are not cheap to produce, requiring skilled personnel and a considerable amount of time. By definition each picture can only ever deal with the view from one location and so are fundamentally inflexible, requiring a complete recalculation if the observation point were to change. ...Another important attribute where photomontages fail, is their inability to depict movement. A moving object on a landscape attracts far greater attention than a static object.”



Figure 3.12: A photomontage of a combined-cycle gas turbine power station⁵⁰.

⁵⁰ Image from TJP Envision Ltd. (2001).

3.3.4.10 Computer Generated Animations

Animations are a dynamic computer simulation method used mainly as a presentation tool to aid the decision making process. They have the advantage over static views in that the development can be visualised from more than a single viewpoint and therefore this can give a better overall picture of what the development will look like. LITIEMA (2002) state:

“Often there is a need to portray complex developments in more detail than can be easily achieved using a single or several photomontages. An example may be where there is a requirement to select a large number of viewpoints, moving perhaps from an aerial to a ground perspective and on into the interior of a building. An animated sequence may also be helpful in explaining the orientation of a site more dynamically than a series of single photographs can achieve.”

The major drawback of animations is that they are fixed to a set path defined by the client or modeller which can lead to bias due to less attractive parts of the development not being shown. Animations can also be very time consuming to produce in both modelling and rendering time. A three minute animation would typically require just under five and a half thousand frames (assuming thirty frames per second). LITIEMA (2002) state:

“...the speed of which (rendering) will depend on the computer's ability to handle multiple calculations of perspective and lighting effects. Changes to the original agreed route through the model at this stage are time consuming and expensive, often requiring a complete re-rendering of the model.”

Depending upon the processing power of the computer used and the final display medium, animations may have to be produced at low resolutions which can lead to low visual acuity, which in turn leads to lower accuracy. Some of the techniques that may be used to produce animations have been briefly described in chapter 2.

3.3.4.11 Virtual Reality

Bulmer (2001) states:

“Virtual Reality models that can be interactively explored will undoubtedly make the visual presentation of ideas and proposals at planning meetings or over the internet far more interesting and understandable for the public. For the process of forward visualisation VR models of urban areas are and will over time revolutionise the public participation process.”

The main advantage of VR for VIA is that the user is not restricted to a set number of views. Using VR, a proposed development can be viewed from any location and this also allows for the development of alternative scenarios. Typically these scenarios may include adding or removing buildings, changing the number of storeys, or adding extra vegetative screening.

VR also has the ability to illustrate change over time from pre-development through to construction and completion. LITIEMA (2002) state:

“Illustrating change over time is frequently important in predicting the degree to which planting may screen a development in the future. Based on growth tables for a known planting mix, the benefit of a tree belt may be shown at say five, ten, and fifteen years growth, while still offering the facility to move freely around the site. This degree of flexibility is a powerful tool for objectively predicting and then mitigating impacts before major changes to site layout prove necessary.”

The major disadvantage of VR systems is with accuracy, hardware limitations, display resolutions and cost (Bulmer, 2001). This is especially true of large complex VR worlds which require a high degree of realism and accuracy, such as those used for VIA. Both advantages and disadvantages of the use of VR have been discussed in chapter 2.

3.4 Factors Affecting Visual Impact Assessment

3.4.1 Surveying 3D Baseline Data

To produce accurate VIAs the 3D baseline data of the proposed site also needs to be as accurate as possible. If data is not readily available at a high enough required detail then the site must be surveyed. There are many methods which can be employed for surveying sites including satellite position fixing, measurement by light and radio waves, imaging from satellites and map production from digital images (University of Melbourne, 1999). However, two of the more common current surveying methods are using manual traditional surveying techniques, or using laser scanning equipment.

3.4.1.1 Manual Surveying

Manual surveying methods include the use of measuring tapes, range finders, electromagnetic distance metertheodolites, levels, tacheometers, sextants, compasses and theodolites (University of Melbourne, 1999). Nowadays, the surveyed data is generally stored in a digital format, usually as a DEM or 2D architect plan. Data in this format is useful if, for example, contoured sections or 3D computer generated models of the site are to be produced. Manual surveying methods are prone to human error and can be extremely time consuming to carry out.

3.4.1.2 Laser Scanning

Laser scanning can be used to quickly create DEMs and DTMs which may include surface features such as buildings and trees (figure 3.13). Ordnance Survey (2001b) describe laser scanning thus:

“Laser scanning uses an airborne laser to capture high accuracy DEMs. The system works by sending a laser pulse from an aircraft to the ground and measuring the time taken for the signal to be returned. This information combined with the precise position and orientation of the laser device when the measurement was taken allows for the

production of a highly accurate DEM.”

High resolution digital images of the survey area can also be taken at the same time as the laser scans. The images are orthorectified using CG image editing software so that they can be accurately draped over the DTM. Laser scanning can also be used at ground surface using a scanner similar to the one shown in figure 3.14.

The advantage of laser scanning is that 3D computer models can be created very quickly for both large or small areas. The disadvantage is that the DEMs and DTMs can be expensive to produce, although it has been illustrated many times that laser scanning can be more cost effective than manual surveying (3D Laser Mapping Ltd., 2001a). Accuracy can also be an issue, with a scan producing too much detail for a simple terrain and not enough detail for more complex terrain features such as buildings and vegetation.

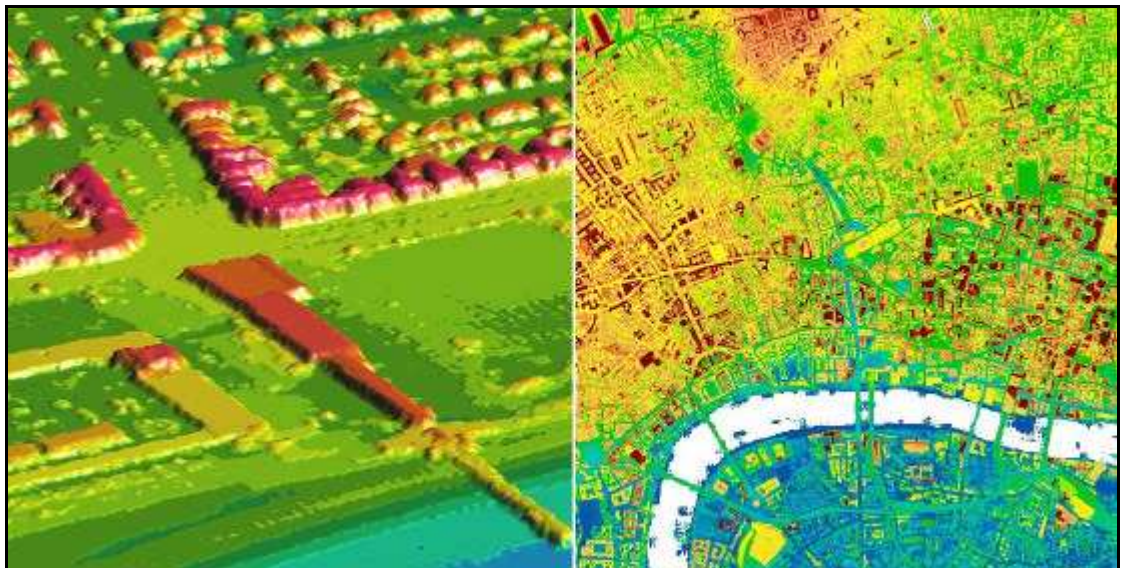


Figure 3.13: Examples of DTMs created by airborne laser scanning⁵¹.

Appendix 3 presents a case study which used laser scanning techniques, similar to those described above, to produce a flood visualisation model for a town called Morpeth.

⁵¹ Image from Ordnance Survey (2001b).



Figure 3.14: Typical long range laser scanner⁵².

3.4.1.3 DEM Accuracy

OS DEM data is often used for the creation of landscape models and is widely employed within the VIA process. However, it is well documented that OS DEM data can have up to a 3 metre root mean square error (Fisher, 1994). The Macaulay Land Use Research Institute (2003) describes the two stage process in the derivation of an OS DEM:

“First the contour lines of maps of a particular scale are digitized. Such contour lines are cartographic approximations of the actual heights of the land surface above the ground. Contour lines do not record precise height locations since they are intended to display information at a particular scale. Heights in only a small fraction of the total area of the intended DEM are recorded in this process.

The values at all other locations are then estimated by an interpolation process. The values are a result of the elevations on the contour lines together with the method used, and the variability of interpolation estimates is well documented elsewhere.”

⁵² Image from 3D Laser Mapping Ltd. (2001b).

3.4.2 Earth Curvature and Atmospheric Refraction

When producing 3D computerised models of large areas for VIA it is important to take into account the effect of Earth curvature and atmospheric refraction. These factors have the effect of lowering a line of sight, which if not taken into account, could result in an inaccurate VIA. Aylward and Turnbull (1977) state:

“Since all topographic data is based on an assumed flat reference plane, usually height above sea level, it is necessary to reduce all elevations from the specified view point to take into account the curvature of the earth and refraction of light, if the survey area is greater than 2 miles (3.2km).”

Figures 3.15 and 3.16 show formulae for the combined elevation loss due to atmospheric refraction and earth curvature by Chester (1999) and NCDOT (2002) respectively. The difference between the two equations is due to the difference in units for the sighting distance and in essence the equations yield the same result.

$z_{ft} = 0.574 d_{miles}^2$	where	z_{ft} = elevation loss (ft) d_{miles} = sighting distance between the observation point and the observer point (miles)
------------------------------	-------	--

Figure 3.15: Equation for the elevation loss due to atmospheric refraction and earth curvature⁵³.

$z_{ft} = 0.0206 (0.001d_{ft})^2$	where	z_{ft} = elevation loss (ft) d_{ft} = sighting distance between the observation point and the observer point (ft)
-----------------------------------	-------	--

Figure 3.16: Equation for the elevation loss due to atmospheric refraction and earth curvature⁵⁴.

Figure 3.17 adapted from Bishop (2002) shows the individual formulae for the determination of elevation loss due to earth curvature and atmospheric refraction respectively. Arnett (2002)

⁵³ Equation after Chester (1999).

⁵⁴ Equation after NCDOT (2002).

states that the diameter of the Earth is 12,756.3 km, which when combined with Bishop's equations gives a combined elevation loss as shown in figure 3.18. This compares well, after unit conversions, with the equations shown in figures 3.15, 3.16. This also compares well with the equation for elevation loss by Jackson and Leong (1993).

$z_c = d_m^2 / D_{km}$	where	z_c = elevation loss due to earth curvature (m)
		d_m = sighting distance between the observation point and the observer point (km)
		D_{km} = diameter of Earth (10^3 km)
$z_r = 0.13 d_m^2 / D_{km}$	where	z_r = elevation gain due to atmospheric refraction (m)
		d_m = sighting distance between the observation point and the observer point (km)
		D_{km} = diameter of Earth (10^3 km)

Figure 3.17: Elevation loss due to earth curvature and gain due to atmospheric refraction⁵⁵.

$z_m = 0.068 d_{km}^2$	where	z_m = total elevation loss (m)
		d_{km} = sighting distance between the observation point and the observer point (km)

Figure 3.18: Equation for the elevation loss due to atmospheric refraction and earth curvature⁵⁶.

Chester (1999) states that the equation shown in figure 3.17 is only correct near sea level and at a temperature of 65 degrees Fahrenheit. This is because the index of refraction of the atmosphere varies slightly depending upon elevation and temperature. Therefore a coefficient of refraction and curvature is required to take into account varying altitudes and temperatures. Figure 3.19 shows Chester's equation with the coefficient of refraction and curvature along with a metric version which has been modified using conversion data by Onlineconversion (2002).

Tables 3.4 and 3.5, adapted from Chester (1999) show the coefficient of refraction and curvature for various elevations and temperatures respectively. For UK conditions a coefficient of Earth curvature and refraction of 0.574 should be used.

⁵⁵ Equation adapted from Bishop (2002).

⁵⁶ Equation by the author (May 2002).

$z_{ft} = b_{Er} d_{miles}^2$	where	$z_{ft} = \text{total elevation loss (ft)}$
		$d_{miles} = \text{sighting distance between the observation point and the observer point (miles)}$
		$b_{Er} = \text{coefficient of refraction and curvature}$
$z_m = 0.1177 b_{Er} d_{km}^2$	where	$z_m = \text{total elevation loss (m)}$
		$d_{km} = \text{sighting distance between the observation point and the observer point (km)}$
		$b_{Er} = \text{coefficient of refraction and curvature}$

Figure 3.19: Equation for the elevation loss due to atmospheric refraction and earth curvature⁵⁷.

Elevation (m)	Refraction and curvature coefficient
0	0.574
305	0.587
3050	0.597
4570	0.606

Table 3.4: Refraction and curvature coefficient as a function of elevation (a temperature of 18.3°C is assumed)⁵⁸.

Temperature (°C)	Refraction and curvature coefficient
-17.8	0.582
-1.1	0.585
15.6	0.588
32.2	0.591

Table 3.5: Refraction and curvature coefficient as a function of temperature (an elevation of 1828.8m is assumed)⁵⁹.

The formulae shown in figure 3.19 should be used in conjunction with topographic data which is based upon a flat plane in order to produce accurate VIAs for areas approximately over three kilometres in length. Not taking the loss of elevation due to earth curvature and atmospheric

⁵⁷ Adapted by the author (May 2002) after Chester (1999).

⁵⁸ Table from Chester (1999).

⁵⁹ Table from Chester (1999).

refraction into account would mean that a potential development would be visualised at a higher elevation than it would in reality.

3.4.3 Seasonal Variation and Growth of Vegetation

Due to the changes in vegetation growth and foliage, changes over time need to be visualised. Vegetation may grow over time and their amount of foliage change through the seasons which could have a direct effect on the screening of a proposed development. There is a large amount of information available on the growth and foliage change of many species of vegetation so it is possible to predict what the vegetation may look like at various points in time. Screening will generally be less effective during the defoliate period, the months between October and March, and most effective during the foliate period, between the months April and September.



Figure 3.20: Photomontages showing vegetative growth over time⁶⁰.

Figure 3.20, taken from IEATLI (1995), shows examples of photomontages which show the change in vegetative screening for a proposed development over time. Many 3D computer

⁶⁰ Image from IEATLI (1995).

graphic software packages are capable of animating vegetation growth and foliage density over time. Such examples include Nat FX (which is a plant modeller for Maya and Discreet's 3D Studio MAX) and Bryce 5 (Prager, 2002).

3.5 Summary

This chapter has introduced the field of EIA and current legislation and has shown the typical processes involved in the creation of an EIA. VIA has been shown to be an important aspect of EIA and current techniques of VIA have been described. Techniques for assessing visual impact can be broadly split into three groups; spatial, quantitative and qualitative. Spatial methods are commonly used in VIAs with FVIs usually employed predominantly. However specialist software is usually required and detailed surface features are often ignored resulting in poor accuracy.

There are currently only a few VIA techniques that are quantitative and Wherrett (2002) suggested that the visual impact is mostly assessed qualitatively since it is concerned with the human appreciation of the landscape. Qualitative approaches, however, may lead to bias due to their inherent subjectivity. Therefore, new and improved quantitative techniques are required in order for a more structured and consistent approach towards VIA.

Important factors that need considering when producing a VIA have also been explained, including data acquisition, the effect of Earth curvature and refraction and the effect of seasonal variation.

CG and VR techniques used for VIAs have been briefly discussed in this chapter. Chapter 4 presents a selection of commercial case studies which apply these and similar techniques to VIAs.

4 Current Use of Computer Graphics and Virtual Reality for Visual Impact Assessment

4.1 Introduction

This chapter presents a selection of commercial case studies which use CG and VR techniques and apply them to VIAs. The chosen case studies are not intended to be all encompassing, but instead have been chosen since they are representative of the current state of the use of CG and VR for VIA and combine to produce a broad range of different solutions to the problems encountered.

The techniques presented include computer visualisations, VR, augmented reality, photomontages and FVIs. No current case studies using any form of computer based percentage view change have been found by the author. The German railway project, a case study produced by the author, has also been included in this chapter to demonstrate how to overcome some of the development time and accuracy problems associated with many of the commercial case studies detailed in the first part of this chapter.

4.2 Virtual Los Angeles Project

4.2.1 Introduction

The Urban Simulation Team at UCLA, in California, USA, is a research group developing applications for real-time visual simulation in design, urban planning, emergency response and education. Although their research is not concerned with VIA, their techniques could provide a useful platform for interactive VIA in the future.

Currently, the Urban Simulation Team's primary focus is to build a VR model of the entire Los Angeles basin which is accurate enough for the graffiti on the walls and signs in the windows to be legible. The simulation system has been proven useful for architectural design development

and city planning since alternatives can be rapidly evaluated in more detail than traditional methods (Jepson *et al*, 1995).

The model is used to interactively fly, drive and walk through the Los Angeles basin and interaction with individual objects can be used to gain extra information about them using links to relevant internet sites. Figure 4.1 shows a view of the Downtown portion of the VR model.



Figure 4.1: Downtown Los Angeles VR model⁶¹.

4.2.2 Methodology

The model is constructed by combining aerial photographs with street level images and 3D geometry. The aerial photographs are used as a base for building the 3D geometry. For many buildings and streets, CAD data is already available from previous designs, which can be used to shorten the time taken for the modelling process. Textures, captured by digitally photographing each building facade, are perspective corrected and colour corrected and then mapped onto the 3D geometry (Jepson *et al.*, 1995).

⁶¹ Image from Urban Simulation Team (2002).

It is estimated that, when completed, the entire virtual Los Angeles will cover an area of over ten thousand square miles and will exceed one terabyte in size. To run such a large VR model specialist hardware is required, hence a Silicon Graphics Onyx workstation with Reality Engine graphics hardware is being used (Urban Simulation Team, 2002).

4.2.3 Analysis

The advantages of this type of VR simulation is stated by the Urban Simulation Team (2002):

“The strength of the simulation system is the elimination of complex blueprints, charts, and other hard-to-understand traditional representational methods. Instead, viewers can easily ‘place’ themselves within a digitally accurate perspective representation of a proposed development and better assess the project’s impact.”

Alternative designs can also be easily viewed and since results of a planning or design process are illustrated visually, the client or community can view and understand the proposed environment without difficulty and hence become informed participants in the decision making process.

The biggest disadvantages of this system for VIA is the cost involved and the time taken to develop the model. Since the model is extremely large, expensive specialist hardware is required to interact with it. Also, it has taken over four years to develop just the Downtown portion of the model.

The disadvantages of the simulation are expanded upon by Bulmer (2001) :

“Although one of the most impressive examples of urban simulations in the world, the model’s functionality as a public participation tool is severely limited for it’s lack of accessibility as its sheer size makes it impossible for internet usage as yet.”

These factors mean that the model can not be easily distributed to potential users whether over the internet or on CD-ROM, for example. It must be noted however, that for many VIAs, a large scale, complex, environment such as this may not be required in order to assess visual impact to a sufficient level of accuracy, hence simpler VR models could be used in many circumstances.

4.3 LSS Terrain Modelling System

4.3.1 Introduction

McCarthy Taylor Systems Ltd. (2002) is an independent software house specialising in 3D terrain modelling software, which is used for a diverse area of applications including VIA. The main software package that can be used for VIA is called Elite, this is a terrain modelling and survey processing application which provides a number of functions for a variety of tasks including: FVIs, vertical field of views (vertical angles), the number of targets seen, static 3D views, the creation of interactive VR simulations and volume calculations (McCarthy Taylor Systems Ltd., 2002). The following sections describe the various VIA functions incorporated in this package.

4.3.2 Fields of Visual Influence

In terms of VIA, the FVI function is useful for determining from which locations a single object can be seen. The user defines the object position in relation to a DTM and either a full 360 degree sweep or an arc between two bearings. The method uses the radial line technique, so the user must also define an angular interval between the calculated lines. The software can also incorporate corrections for Earth curvature and refraction if required. Once the FVI has been produced, the resulting image can be displayed on top of the original survey data or an aerial photograph to give a clearer picture of the FVI.

4.3.3 Vertical Angles

The vertical field of view taken up by a development from a selected viewpoint can be determined using Elite. A number of viewpoints can be selected as a grid, the software will then calculate the vertical angle of a specified target for each viewpoint and the results are displayed as a series of isopleths (contours).

4.3.4 Number of Targets Seen

Elite can also determine the number of targets which are visible from a selected receptor. A number of these calculations can then be combined to produce a grid of receptors showing the number of visible targets (one of these grids was shown in figure 3.7 in the previous chapter). This function is very useful for assessing developments with individual, intrusive components such as wind farms.

The above method does not specify which objects are visible from specific locations. Therefore the software has a function for determining which objects are visible from a selected viewpoint by radiating lines towards every visible target (figure 4.2).



Figure 4.2: Radial lines indicate which objects are visible from a selected viewpoint⁶².

⁶² McCarthy Taylor Ltd. (2002).

4.3.5 Virtual Reality Simulations

3D Vantage is a VR simulation package which can be used to interact with 3D models created using McCarthy Taylor's various 3D modelling packages. The user can freely navigate around the virtual world or can be taken on a pre-defined flight path. 3D Vantage also allows individual models to be turned on and off, which is very useful for conveying different development proposals. Figure 4.3 shows a screenshot of the 3D Vantage interface with a 3D model of a proposed quarry development.

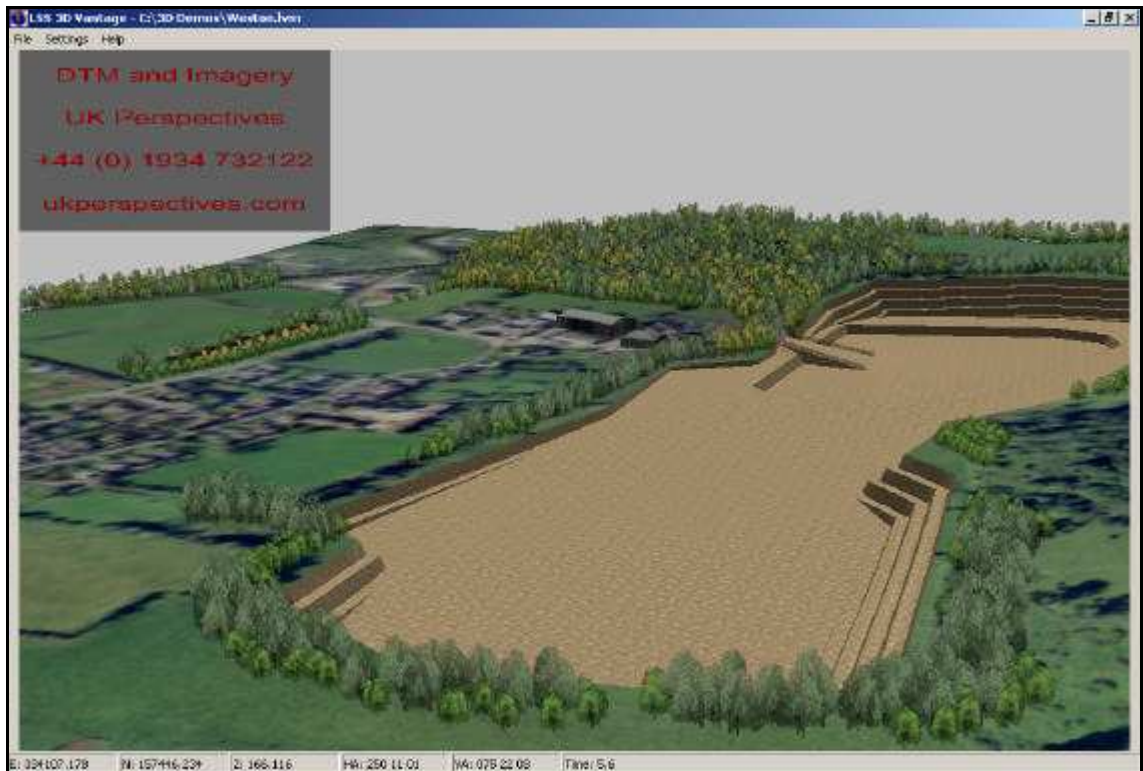


Figure 4.3: 3D Vantage Interface⁶³.

4.3.6 Analysis

McCarthy Taylor Ltd. have produced a number of software packages which can be used to help with the assessment of visual impacts. Elite can be used to determine FVIs, fields of view and an analysis of the number of targets that can be seen. 3D Vantage can be used as a real time

⁶³ Image from McCarthy Taylor Ltd. (2002).

virtual viewer of models created in Elite and other various software packages developed by McCarthy Taylor Ltd.

The advantage of using their software is that they can take into account Earth curvature and atmospheric refraction and simple surface features such as buildings and trees. These factors increase the accuracy of the numerous VIA tools that the packages contain. Another important advantage is that the software packages run on a standard desktop computer and the 3D Vantage VR package is free to distribute. Therefore third parties can view and interact with a proposed development with no excessive costs involved.

There are also a number of disadvantages with the software packages. FVIs are created using the radial line method, which means that accuracy decreases as the radial lines diverge. Also, FVIs can not be created for large scale developments such as quarries since an FVI would potentially have to be created for every point on the quarry. This is a problem for most commercially available computer based FVI software packages.

Primarily, McCarthy Taylor Ltd.'s software packages are not used as 3D modelling tools (although they do allow the import of AutoCAD files) and hence the accuracy and realism of the 3D models which can be created is limited. This has a direct effect on the accuracy of the VIA methods employed and the realism conveyed in their VR simulations.

4.4 LandScape Information System

4.4.1 Introduction

LSIS, developed by Kyushik Oh, was produced for the purpose of managing urban landscape information and analysing the visual impacts of proposed development projects by employing GIS and CG simulation techniques (Oh, 2001).

4.4.2 LSIS Database

The core of LSIS is based on AutoCAD Map (AutoDesk, Inc., 2002d) which can run on a standard desktop computer. The database for LSIS can contain various information on the landscape and this is shown in table 4.1. This table is discussed in more detail by Oh (2001).

Landscape types Landscape elements		Baseline landscape	Skyline and streetscape	Landscape (building) envelope
Land base / Land form	Topography and geology	Topography and geology		
	Roads	Roads and sidewalks		
	Lot areas			Lot boundaries
	Architectural and urban planning controls			Zoning, lot coverage, FAR, building spacing and height, setback, other architectural and planning controls
Land cover / Related developments	Trees and vegetation		Trees and vegetation	
	Road facilities		Overpasses, overhead bridges, streetlights, signal lights, electric poles	
	Buildings and Structures		Single or detached houses (low-rise), apartments (high-rise), office buildings, factory buildings, temporary buildings, other structures	
	Proposed developments		Development proposals	
Landscape management	Viewpoints for landscape control	Viewpoints (3-D coordinates)		
	Landscape resources	Landscape resources		
	Development limits	Development limits / thresholds (VTCC)		

Table 4.1: LSIS database information related to urban landscape elements and their management⁶⁴.

Oh (2001) used the city of Seoul, in Korea, as a case study to showcase his work. Data such as topography, roads, buildings and land ownership were acquired from Seoul's information database. Data which were not available in Seoul's database were acquired from other individual sources. The LSIS GIS database could then be used to produce a simple CG 3D wire mesh model of the city which contained information about the relationships between graphic data and attribute and image data.

⁶⁴ Table taken from Oh (2001).

4.4.3 Fields of Visual Influence and Visualisations

To produce a visual impact analysis, the proposed project is modelled in 3D and merged with the existing LSIS database model. The software then produces an FVI which indicates which areas on a 2D plan can see the new development (figure 4.4).

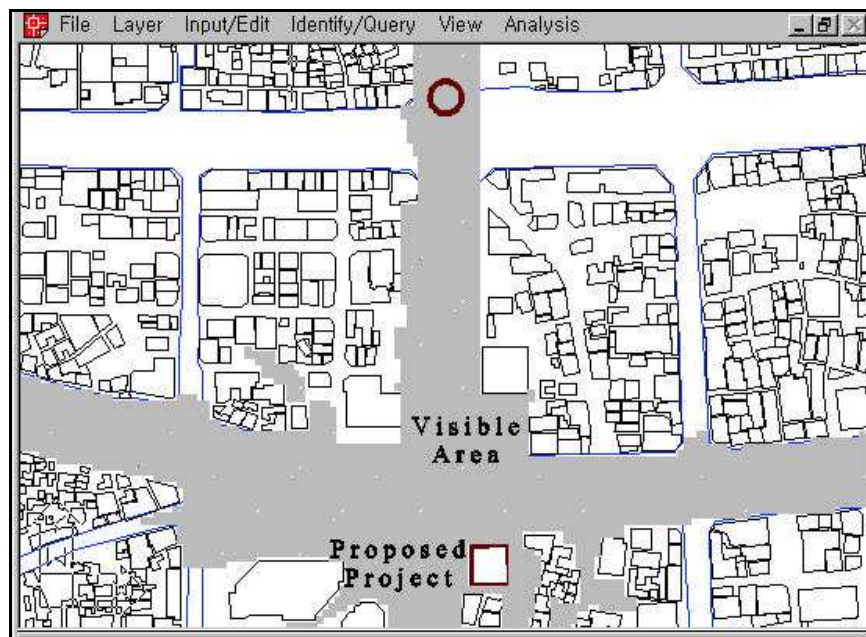


Figure 4.4: FVI of a proposed project⁶⁵.

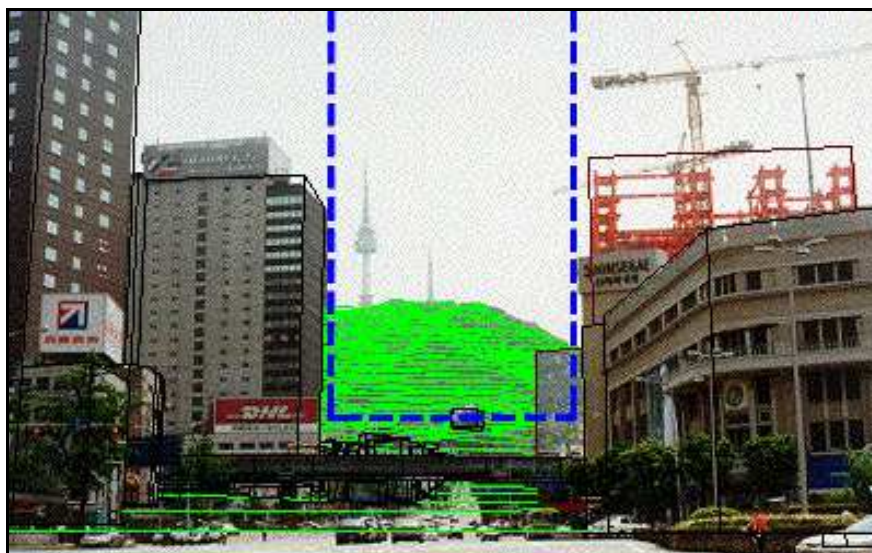


Figure 4.5: Photomontage of proposed development⁶⁶.

⁶⁵ Image from Oh (2001).

⁶⁶ Image from Oh (2001).

A 3D perspective can then be constructed for each critical viewpoint which lies within the FVI. This perspective is then superimposed onto a photograph of the existing landscape (figure 4.5). The green lines indicate the topography of the ground, the black lines represent existing buildings and structures and the red lines indicate the proposed developments. As figure 4.5 shows, one of the proposed buildings is already under construction (the red steel work).

4.4.4 Analysis

Although this system is easy to implement, the techniques used result in abstract landscape images (Oh, 2001). The major disadvantage with the system, however, is the lack of accuracy due to the simplified 3D wireframe model used. This has a direct effect on the accuracy of the FVI and the 3D perspective view. Surface features, such as vegetation, are not taken into account, and since the model is not created using a 3D modelling software package, the detail of the overall model is not high enough to produce accurate and reliable results. Figure 4.5 demonstrates this by missing a number of building details such as the top of the far tower block on the left. Although this does not directly affect this case study example, such details may be important in other cases.

Another disadvantage with LSIS is that it does not take account of the Earth's curvature and atmospheric refraction. For relatively small scale projects this is not a problem, but if LSIS is to be used for large scale projects which involve several square kilometres of environment then these factors need to be taken into account.

4.5 ArcView

4.5.1 Introduction

ArcView is a popular desktop GIS and mapping software package which currently retails for approximately £1000 and is able to perform many GIS tasks, including data visualisation,

query, analysis and integration capabilities along with the ability to create and edit geographic data (ESRI, 2003a).

Several optional software extensions are available for ArcView which provide additional application specific functions. One extension, ArcGIS 3D Analyst which currently retails for approximately £1700, provides advanced tools for 3D visualisation, analysis and surface generation (ESRI, 2003b). One important tool within ArcGIS 3D Analyst is the viewshed function which is described in more detail below.

4.5.2 Fields of Visual Influence

The viewshed (also known as an FVI) function within ArcGIS 3D Analyst allows the user to determine visibility on a surface from point to point along a given line of sight, or across the entire surface in a viewshed (ESRI, 2003b). The program is capable of determining both reflective and projective FVIs, and the GIS software can combine a number of FVIs to produce cumulative FVIs.

In order to produce FVIs for large scale developments, such as a quarry or power plant, where each point on the development requires viewshed analysis, the program simplifies the procedure by assessing the visibility of a number of points positioned around the development. For example, to produce an FVI of a power plant, the user can define a set of observation points around the power plant's exterior and for each point, a projective FVI is then determined. The results for each of the points can be combined in such a manner as to produce a cumulative projective FVI which shows the percentage of the points on the power plant which can be seen from any point in the study area.

A cumulative projective FVI of this type is shown in figure 4.6 which was created using the ArcView GIS software package. The image shows an FVI of a quarry (outlined in green) which

was produced by determining projective FVIs for a number of points placed around the quarry perimeter and then combining these individual FVIs. In this example, the visual impact of the quarry has been directly linked to the percentage of points on the perimeter of the quarry which can be seen from the surrounding environment.

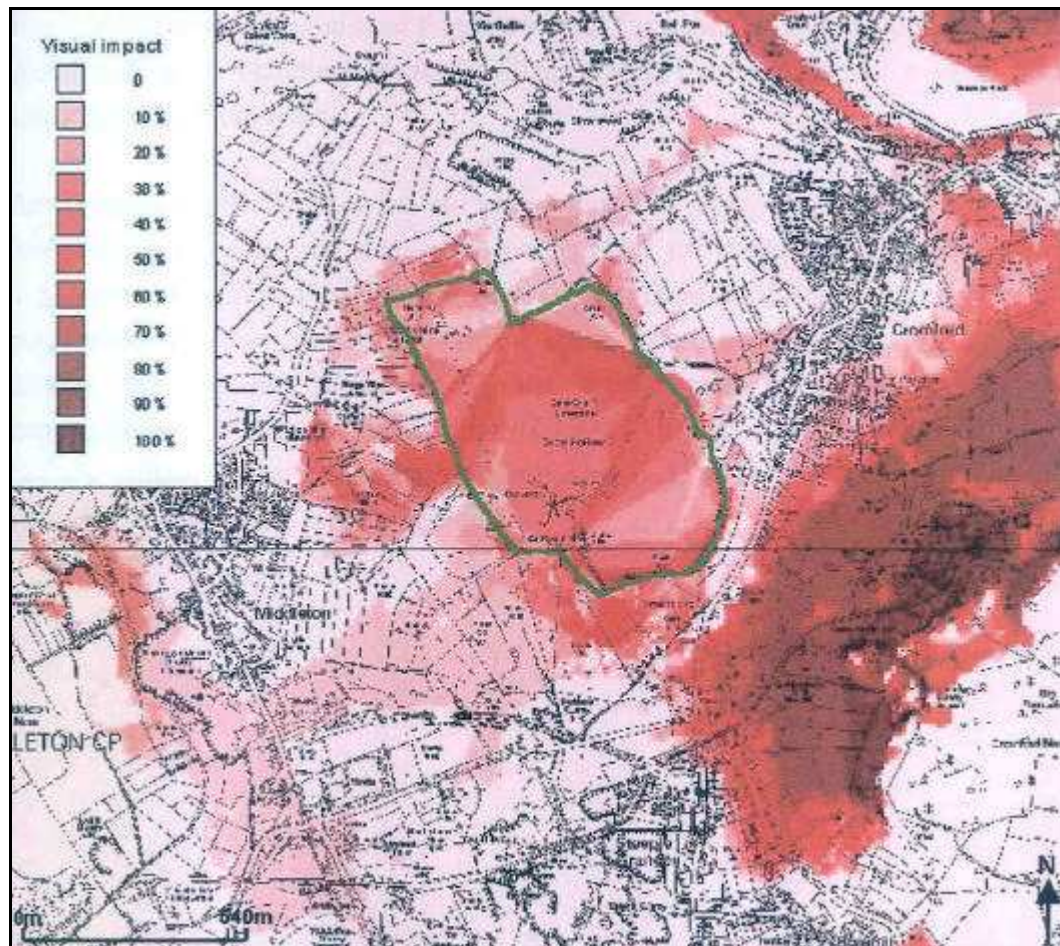


Figure 4.6: A cumulative projective FVI of a quarry⁶⁷.

4.5.3 Analysis

ArcView, with the extension ArcGIS 3D Analyst, is a popular GIS which is used worldwide and amongst its various features is a function capable of producing reflective, projective and cumulative FVIs. The software is also able to take into account of Earth curvature and atmospheric refraction and simple surface features such as blocks of buildings and trees.

⁶⁷ Image from Platt (2002).

However, the two software packages have a combined retail value of approximately £2700 and they do not take account of more detailed surface features such as individual buildings and semi-transparent vegetation. Another major drawback to this GIS is that cumulative projective FVIs are created using a number of individual observation points which do not give a true representation of the development. For example, a viewpoint may be able to see part of a development which has not been linked to an observation point and although the development can be seen, the resulting FVI may show that the development cannot be seen at all from that viewpoint. Another problem with this method is that a viewing location may be able to see fifty percent of the observation points along the perimeter of the quarry, but this does not mean that fifty percent of the quarry can be seen. The determination of cumulative projective FVIs using currently available software techniques is not an easy task and this problem is discussed further in chapter 5.

4.6 GIS Based Augmented Reality

4.6.1 Introduction

Ghadirian and Bishop (2002) presented their ideas for an augmented reality system capable of showing the possible spread of weed through the Cudgewa Valley in rural Victoria, Australia. Their ideas are not directly linked to visual impact but rather to visualise environmental change. However, using their augmented reality system, it should be possible to visualise change to the appearance of an environment, and hence the impact, from a proposed development.

4.6.2 Methodology

Ghadirian and Bishop's initial research uses three identical video cameras, positioned side by side, to capture wide screen video sequences of real world environments, such as the Cudgewa Valley (for which they plan a pilot study) and using a Global Positioning System (GPS) the changing locations of the cameras is recorded. The three video sequences obtained from the

three cameras is then composited together using video editing software to produce one high resolution wide screen video sequence (figure 4.7).

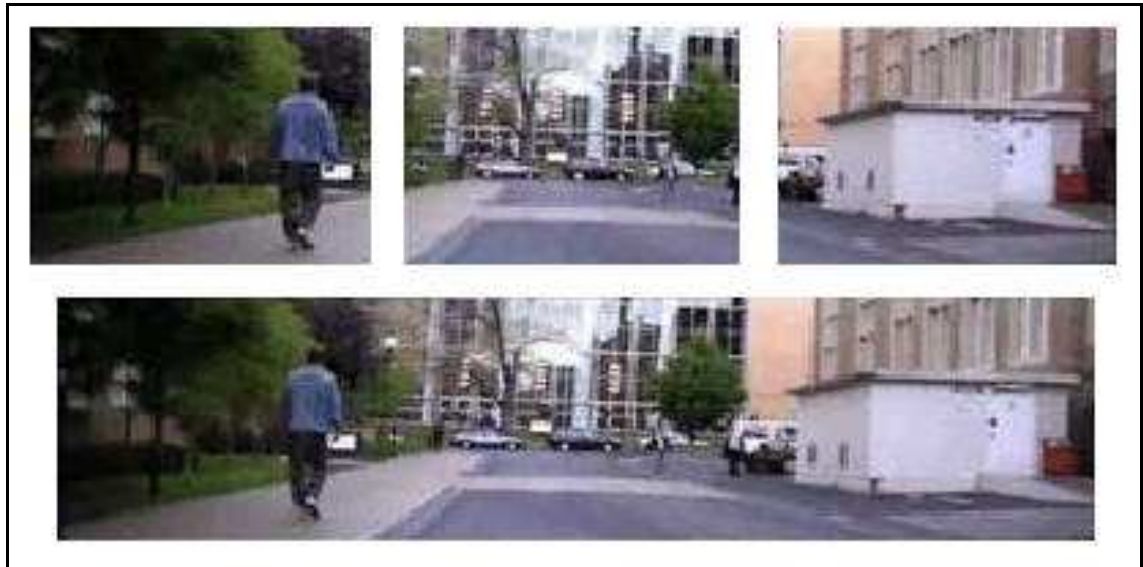


Figure 4.7: The three video sequences (top) are composited to produce a single sequence (bottom)⁶⁸.

The programming language, Visual Basic for Applications, is used within the GIS software, ArcGIS, to produce weed spread models for a number of different scenarios (figure 4.8). The weed spread model data is then imported into 3D Studio MAX and, using a combination of modelling techniques and texturing, a 3D CG model of the weeds is produced. With the terrain model of the environment coloured blue, animations for each weed spread model is produced along the same path as the video sequence using the GPS spatial data recorded for the cameras (Ghadirian and Bishop, 2002).

The video of the real environment is then merged into the various animations using a chroma-key process in order to hide the terrain model from view. This results in a number of augmented video sequences showing the weed spread model superimposed over the real world environment. To create a realistic viewing atmosphere, the wide screen video sequences are projected onto three screens which gave a total projection width of 7.2m and a 135 degree

⁶⁸ Image from Ghadirian and Bishop (2002).

horizontal field of view (Ghadirian and Bishop, 2002).

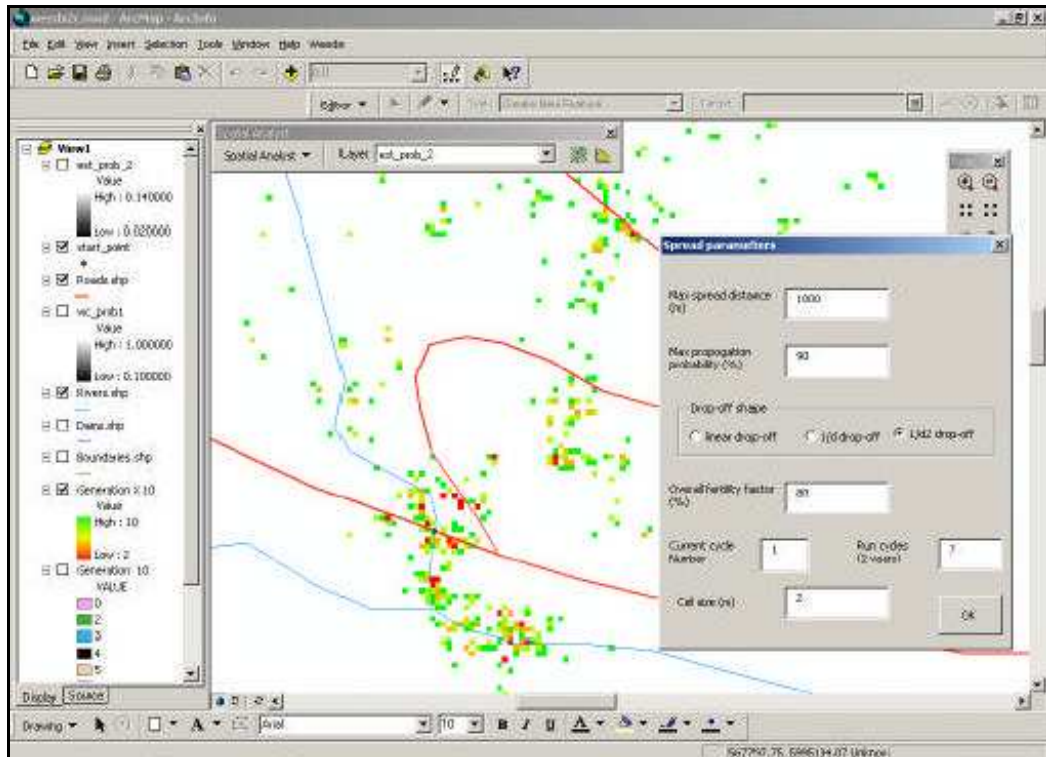


Figure 4.8: Screenshot of a weed spread model within ArcGIS⁶⁹.

4.6.3 Analysis

At the time of presenting their work in their paper in 2002, Ghadirian and Bishop had not realised their ideas but a pilot study for the Cudgewa Valley was planned. Augmented reality has allowed Ghadirian and Bishop to theorise a technique for realistically and accurately visualising changes to the environment and it may be possible for their system to assess visual impacts arising from potential developments.

Their technique involves the use of video sequences and this has a direct drawback in that viewers can only visualise the environment from set locations and pathways, which could lead to bias if used for VIA. This system may therefore produce subjective results since different viewers respond differently to visual change.

⁶⁹ Image from Ghadirian and Bishop (2002).

4.7 GIS Based Virtual Reality

4.7.1 Introduction

Stock and Bishop (2002) have developed a landscape simulation model that allows a user to explore alternatives to the existing landscape in an interactive, immersive virtual environment. They have used the Cudgewa Valley, located in Victoria, Australia, as a case study for their work which involves the use of GIS and VR technology.

4.7.2 Methodology

A detailed 3D model of the Cudgewa Valley environment is rendered in real-time, using OpenGL Performer, onto three screens using three projectors to give a 135 degree field of view. Each of the three projectors is connected to a desktop computer and the three desktop computers are all connected to a fourth computer which acts as a server. Also connected to the server is a fifth computer running ArcGIS which supplies land cover information to the system. A number of Personal Digital Assistants (PDAs) can also be connected to the server in order for users to interact with the system (Stock and Bishop, 2002).

A virtual model of the Cudgewa Valley was modelled, including features such as terrain, buildings, trees, fences and roads, using data exported from ArcGIS that was obtained from Victoria's department of Natural Resources and Environment (Stock and Bishop, 2002). Figure 4.9 shows an image of part of the environment which was modelled.

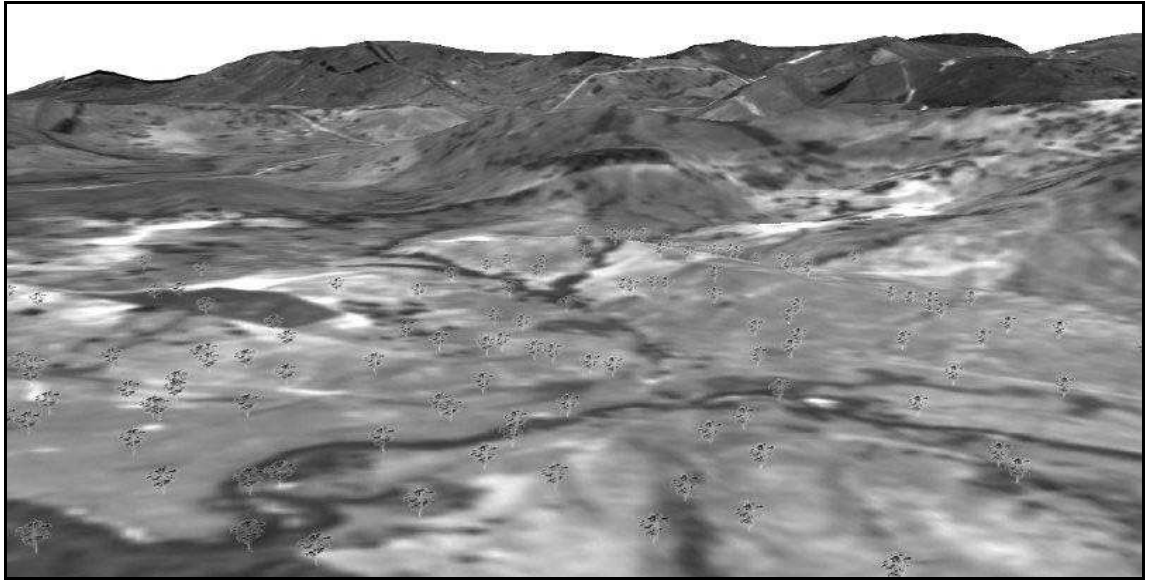


Figure 4.9: Image of the Cudgewa Valley⁷⁰.

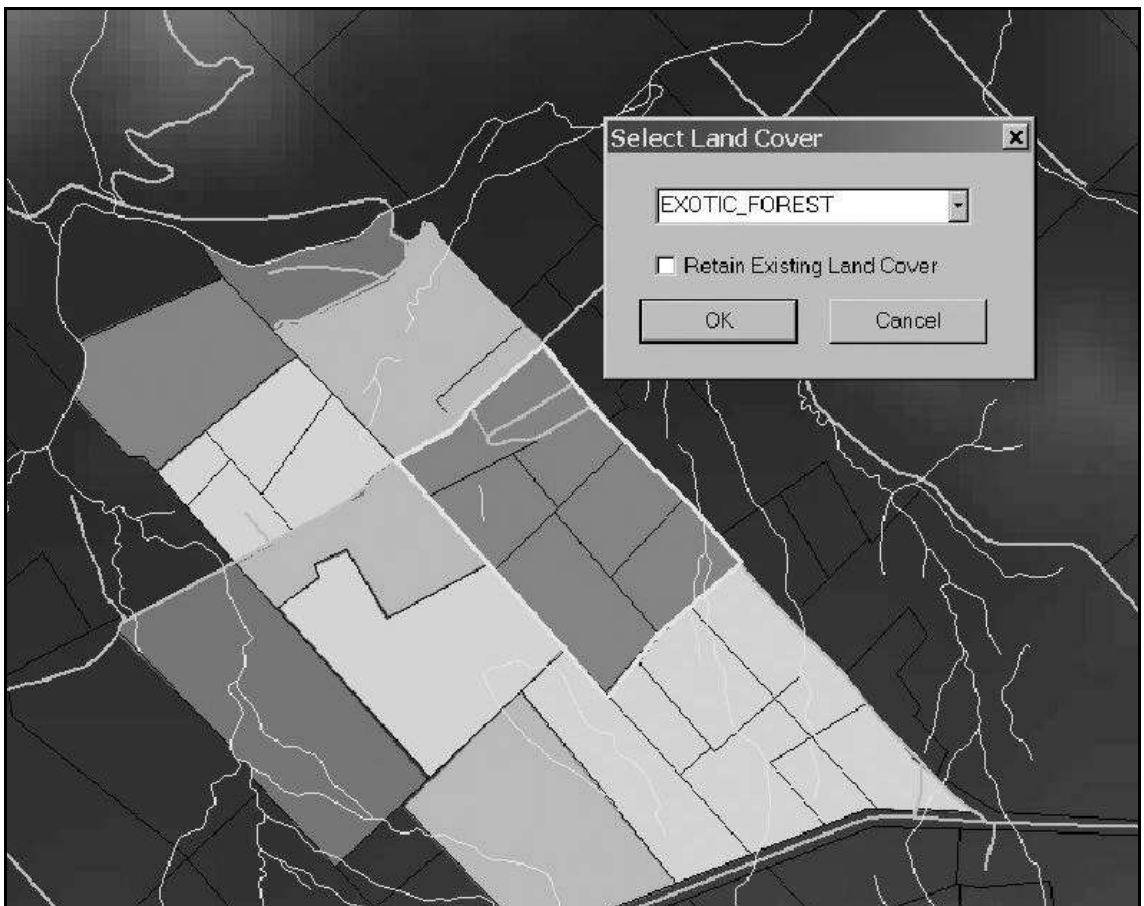


Figure 4.10: The ArcGIS interface⁷¹.

⁷⁰ Image from Stock and Bishop (2002).

⁷¹ Image from Stock and Bishop (2002).

To simulate potential changes in the landscape, Stock and Bishop divided the study area into management units which can be changed to an alternative predefined land cover type. Using a PDA from within ArcGIS, the user can click on any management unit and a dialog will appear showing the various possible land cover types to choose from (figure 4.10). The scene will then be updated to display the new scenario and figure 4.11 shows the marginal farmland shown in figure 4.9 replaced with a pine plantation.

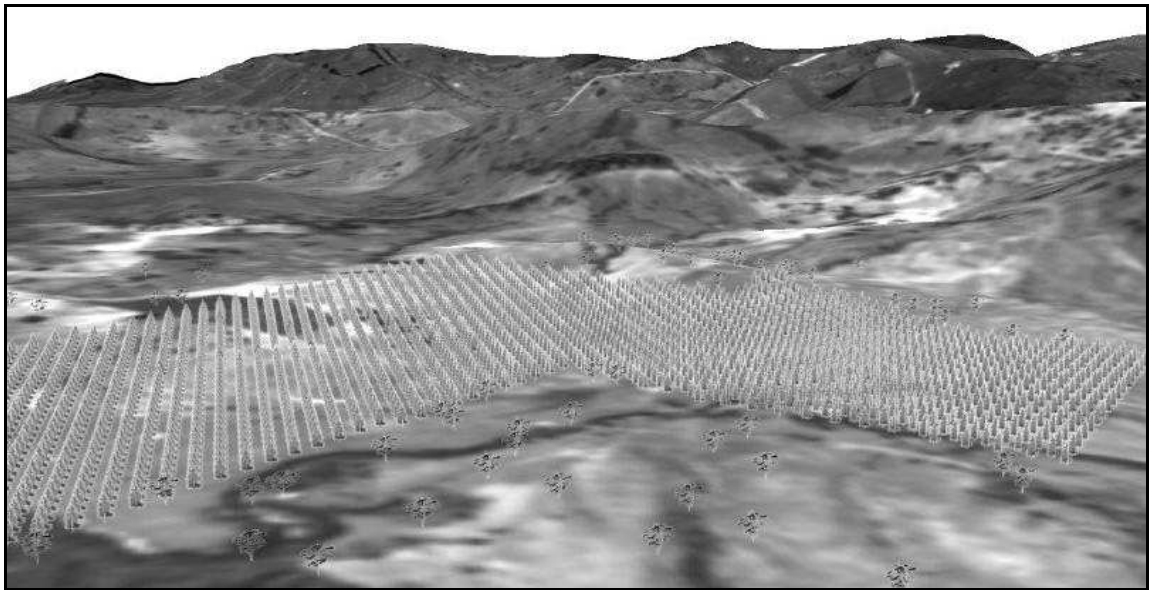


Figure 4.11: Image of Cudgewa Valley with a forest selected as an alternative land cover type⁷².

4.7.3 Analysis

Stock and Bishop (2002) have created a landscape simulation model which allows the users to explore alternative landscape environments and assess and express their opinion on the outcome. To achieve this a combination of GIS and VR technology has been used.

As well as having the ability to demonstrate their own ideas via interaction with the model, users can freely navigate around the environment and are not restricted to set viewpoints. However, the use of this GIS system has limited the detail and complexity, and hence realism, of the 3D model which may of not been the case with a model produced using a 3D modelling

⁷² Image from Stock and Bishop (2002).

package. Stock and Bishop's GIS and VR system is also qualitative and does not provide the ability to perform either spatial or quantitative analysis on alternative land cover scenarios.

4.8 German Railway Project

4.8.1 Introduction

This was a short project, produced by the author on behalf of AIMS Solutions Ltd. at the University of Nottingham, to develop a 3D model of a section of a proposed railway in Germany. The 3D model would then be used to visualise the visual impact of the proposed railway section on the neighbouring environment.

4.8.2 Data Acquisition

3D Laser Mapping Ltd., a Nottingham based surveying company, performed an airborne laser scan of the area in question and took high resolution aerial digital images of the proposed German railway site. Using TerraScan (Terrasolid Ltd., 2002), a software package for processing laser scanning points, Dr. Graham Hunter from 3D Laser Mapping Ltd. classified the point data into three layers; surface terrain, buildings and vegetation.

The digital image of the site was ortho-rectified using TerraPhoto (Terrasolid Ltd., 2002) and saved as a high resolution ECW file. Figure 4.12 shows images of the laser scan point cloud and the ortho-rectified aerial digital image.

Using AutoCAD Land Development Desktop (Autodesk, Inc., 2002e), Mr. Jez Noond, from AIMS Research, triangulated the surface terrain point data into a 3D wireframe mesh (figure 4.13). The building and vegetation height data were also converted from the point data into simple wireframe meshes to use as a guide for the 3D modelling of those features. The wireframe meshes were saved and exported as AutoCAD DWG files.



Figure 4.12: Laser scan point cloud and the ortho-rectified aerial image of the proposed site⁷³.

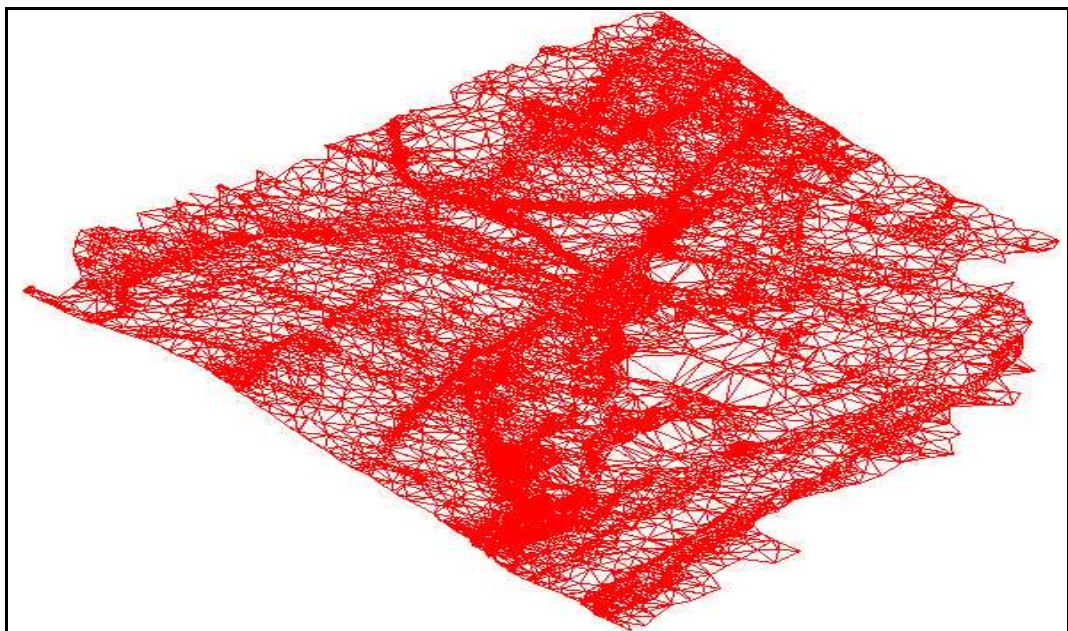


Figure 4.13: 3D wireframe surface terrain mesh⁷⁴.

⁷³ Laser scan and aerial photography by 3D Laser Mapping Ltd. (2002).

⁷⁴ 3D model created by Mr. J. Noond of AIMS Research (February 2002).

4.8.3 3D Modelling and Texturing

The surface terrain mesh was imported into 3D Studio MAX version 3.1 and the digital aerial image was ortho-rectified and draped over the mesh using planar mapping coordinates. The aerial image and the terrain surface were matched up by using reference points and distinguishing terrain features such as building locations.

For most of the buildings, splines were traced around the building outlines and extruded. To each extruded building shape, a roof was then added. For other buildings, a combination of extruded splines and modified boxes were used. The height of the buildings was derived by importing the building height data mesh and using it to control the extrusion of the splines. Individual roof textures were created from the aerial image and mapped onto the building roofs. Since there were no available ground level images to show the sides of the various buildings an unobtrusive brick texture was added.

The 3D Studio MAX software plug-in “Forest Pro” was used to model vegetation planes (2D single faced objects) and manipulate them so that they always faced the camera (Forest Pro is described in more detail in appendix 1). Planes were used for vegetation instead of complicated 3D vegetation models since the number of faces for a forest of planes is minimal compared to the number of faces required for a forest of 3D plant models, hence rendering time can be kept to a minimum. Another advantage of using planes is that realistic vegetation textures can be applied to planes, whereas textures can not be easily applied to complex 3D tree models. As with the buildings, the vegetation height data was determined from the imported vegetation mesh.

The river which runs alongside the railway track was created using a single 2D plane. A portion of water from the aerial image was saved as a separate bitmap image and modified using Paint Shop Pro so that it could be seamlessly tiled when mapped onto the river object. To create the

effect of moving waves, an animated noise map was also added to the material property. Vehicles and trains were also added to the model some of which were animated along motion paths. Figure 4.14 shows a rendered image of the completed model.



Figure 4.14: Rendered image of the German railway⁷⁵.

The model was used to produce a number of rendered static images and animations from various critical viewpoints in order to assess the potential visual impact of the railway extension. Figure 4.15 shows one of the critical viewpoints looking towards the railway station from a nearby building window.

⁷⁵ 3D model by the author (February 2002).



Figure 4.15: Rendered image from a critical viewpoint⁷⁶.

4.8.4 Analysis

Using DEM data derived from airborne laser scans and aerial photographs a detailed, realistic model of a large environment was produced in just over a week. Static images and animations were then rendered from numerous critical viewpoints to assess the potential visual impact of a proposed development. The images and animations obtained from this 3D CG model can easily be distributed on CD-ROM or over the internet. Appendix 4 contains a leaflet created by AIMS Solutions Ltd. to present the German railway case study.

This type of VIA is qualitative and is therefore subjective. The visualisations should be combined with other methods of VIA such as FVIs which would be useful for indicating areas which can or can not see the proposed railway track extension. These techniques will be

⁷⁶ 3D model by the author (February 2002).

discussed in more detail later in this thesis.

Case studies described later in this thesis demonstrate how these modelling techniques can be accurately applied to 3D CG models of this type. This German railway model is also presented in further detail in chapter 5 to illustrate a new FVI technique which overcomes some of the problems with the currently available methods.

4.9 Summary

A number of examples of the current use of CG and VR for VIA have been described each with their advantages and disadvantages. It has been shown that there is scope for improving the techniques currently used for VIA.

The Urban Simulation Team have developed a vast VR simulation system that is both accurate and realistic but its sheer size restricts it to specialised computer hardware and hence the model is not easily distributed. McCarthy Taylor's LSS simulation software, on the other hand, is quite the opposite. Their VR simulation software runs on a standard desktop computer and the VR viewer, 3D Vantage, is free to distribute. However, their software is not designed for accurate, realistic 3D modelling and hence their simulations may not give a true representation of a proposed development. A VR simulation system that incorporates accuracy with ease of distribution would be beneficial for VIA.

For the creation of FVIs, McCarthy Taylor's Elite is a suitable tool for VIA since it takes into account Earth curvature and refraction and simple surface features. Elite can also determine the number of target that can be seen from a selected viewpoint. The disadvantages of this software is its accuracy. The FVIs are created using the radial line method which has been shown to produce inaccurate results with distance and although the software accounts for surface features, the features are often not detailed enough to give reliable and accurate results. As previously

mentioned, this is primarily due to the software not being suitable for accurate 3D modelling.

LSIS suffers similar disadvantages to McCarthy Taylor's software in that the accuracy of the 3D models used have been simplified for the benefit of uncomplicated implementation. The FVIs produced are straightforward to visualise, but the inaccuracy of the model could give rise to false assessment. Also, the photomontages derived from LSIS are abstract and do not give the user a realistic view of how a proposed development might fit in with the surrounding landscape. To produce accurate FVIs an accurate and reliable 3D model would be beneficial and a simple method to produce an accurate FVI from the model needs to be developed in the author's opinion.

The viewshed function within ArcGIS 3D Analyst, an extension of ArcView, has been briefly described and its advantages and disadvantages briefly explained. Benefits include the ability to easily create FVIs with Earth curvature and atmospheric refraction being taken into account if necessary. However, surface features such as trees and buildings are defined as simple geometric shapes since the software cannot import detailed models from 3D CG modelling packages efficiently, and as a result the FVIs produced may not be very accurate. Inaccuracies may also arise from the creation of cumulative projective FVIs which assess the visibility of user defined observation points which are spread out around the proposed development instead of assessing the visibility of the whole development. Another disadvantage with using the GIS software is that the two packages combine with a retail price of approximately £2700 which firmly puts these packages in the "high-end" market.

Although their work has not been fully implemented, Ghadirian and Bishop (2002) have presented a system which combines GIS, GPS and augmented reality that will visualise changes to the appearance of an environment. However, their system is qualitative and restricts users to predefined views and pathways which can lead to bias. With further research, Ghadirian and Bishop could improve their system to allow for unrestricted navigation around an environment

and implement some spatial or quantitative methods for visualising environmental change.

Using the same case study area as Ghadirian and Bishop (2002), Stock and Bishop (2002) have developed a system which combines GIS and VR technology to produce an interactive real-time landscape simulation. This system allows for unrestricted movement within a 3D environment and users are able to change land cover types via interaction with PDAs within an ArcGIS user interface. The downside to Stock and Bishop's GIS and VR system is that the realism and accuracy of the models is restricted due to the processing power of the display mediums used.

The German railway project showed the benefit of using laser scanning to quickly produce accurate DEM data which can then be used for the rapid production of an accurate 3D terrain model and its associated surface features. The 3D model was used to produce animations and static images of a selection of critical viewpoints.

The qualitative VIA techniques which have been presented in this chapter should be combined with both quantitative and spatial techniques to produce a VIA that can be used to help decision makers, residents and other parties involved with the proposed development, assess the likely visual impacts of the development in a clear concise manner.

This chapter has shown that there is a need for current quantitative and spatial VIA techniques to be developed and improved upon. Chapter 5 describes some of these new and improved techniques which have been developed during this research that use 3D models such as the German railway model (described in this chapter) and the Morpeth flood visualisation model (presented in appendix 3).

5 Development of New Techniques

5.1 Introduction

This chapter describes the development of enhanced CG based techniques for VIA, namely FVIs and percentage view changes, and describes techniques which can be used in VIAs that consider earth curvature and atmospheric refraction and the effects of seasonal variation on vegetation. The use of VR to integrate existing VIA techniques and the novel CG techniques which have been developed is also discussed. The software used for the development of these techniques are described in appendix 1.

5.2 Field of Visual Influence Technique

5.2.1 Introduction

As shown in chapter 3, many current FVI techniques are flawed in some respect, with the majority of problems due to accuracy and the large amount of time spent producing output. Hence CG based techniques which can quickly generate accurate FVIs using non-specialist FVI software would be an advantage. Accuracy is the most important issue for FVIs and hence detailed surface features and if applicable, the effect of Earth curvature and atmospheric refraction, must also be taken into account. 3D Studio MAX R3.1 was used for the development of the new FVI technique, although many of the other similar commercially available 3D CG modelling software packages could have been used.

5.2.2 Methodology

The following section details the creation of reflective, cumulative reflective, projective and cumulative projective FVIs using CG techniques. As described in chapter 3, reflective FVIs can be described as what someone can see from a single viewpoint and cumulative reflective FVIs represent what a number of people can see from a variety of viewpoints. Projective FVIs,

however, represent which areas can see a specific reference point and cumulative projective FVIs show the areas which can see a number of reference points.

The FVI techniques developed during this research are based upon the shadows created by virtual lights, in that if a virtual light is placed at a viewers location, areas which are in shadow cannot be seen by the viewer but areas in light can be seen. The basic idea behind this technique was first theorised by Dr. Robin Hollands of AIMS Research and his ideas have been implemented and his initial work improved upon by the research in this thesis. Although the techniques are slightly different for each type of FVI, the initial procedure is the same for all four types of FVI.

An accurate 3D CG model of the proposed site and its surrounding environment should first be modelled. Depending on the use of the FVI, the model could represent pre-development, during development, or post development stages. Detailed surface features such as semi-transparent vegetation should also be included since the following technique allows for such features to be incorporated in the analysis. Table 5.1 lists some factors which should be taken into account before producing an FVI using these techniques.

Factors	Reason
All lights should be turned off including ambient lighting.	Any other lights in the scene may light up areas which cannot be seen from the selected viewpoint.
Ensure all objects are allocated a bright colour.	Dim areas due to shadows and dim areas due to dark coloured objects may become confused.
Reflective materials should be removed.	Objects with reflective properties may contribute unwanted secondary lighting.
All objects should be set to receive light and also to receive and cast shadows.	Since the technique is based upon the casting of shadows, virtual objects need to be able to cast and receive shadows.
Special effects should be turned off (fog for example).	Special effects, such as fog and volumetric lights, could interfere with the light and shadow properties.
Anti-aliasing should be turned off.	Anti-aliasing (as described in chapter 2) will blur the edges of shadows which will not give a clear indication of whether an object is in or out of shadow.

Table 5.1: Factors to take into account to produce an accurate FVI.

5.2.2.1 Reflective Field of Visual Influence

Figure 5.1 shows an image of a car rendered from an example viewpoint which represents a person's view of that car. In order to produce a reflective FVI from this viewpoint all lights were turned off and both the car and the ground had a bright white texture applied in order for any dimly coloured textures not to be mistaken for shadows. For this example, it has been assumed that the windows are opaque and as such do not let light through.



Figure 5.1: View of car from a selected viewpoint⁷⁷.

An omni light was then placed at the camera's location, which represents the person's viewpoint, and given a high luminance value, in order to achieve a hard edged shadow, and its attenuation (the way the light diminishes over distance) turned off. Shadow parameters were set to ray tracing (a technique used to produce shadows by tracing the path of rays sampled from the light source) since this technique is accurate and produces hard shadow edges.

⁷⁷ Image from a 3D model created by the author (January 2003).

The image shown in figure 5.2a shows an FVI, the result of rendering the scene from a plan view. The black shadow zones represent areas which cannot be seen from the viewer's locations, whilst the bright zones represent areas which can be seen. This basic FVI image can now be manipulated using standard image editing software to produce a more readily understandable plan view FVI as shown in figure 5.2b. The viewer's location is shown by the yellow arrow and the areas of the scene which can be seen from that location are shown by the blue shading.

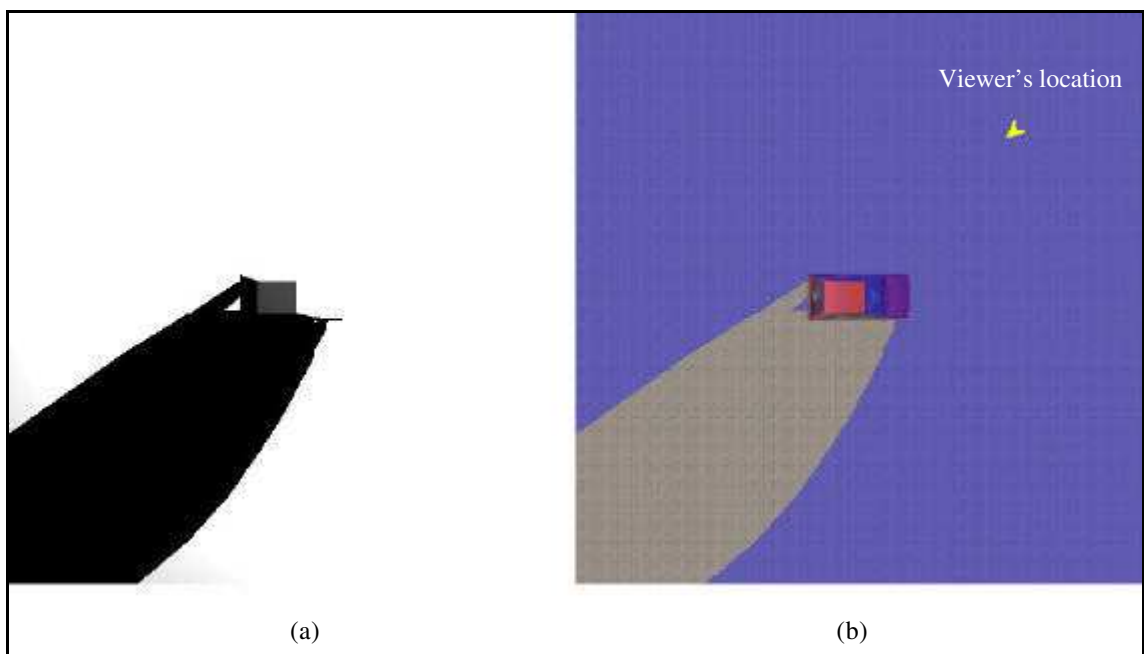


Figure 5.2: Basic FVI produced by rendering plan view of scene (a) and manipulated FVI (b)⁷⁸.

This reflective FVI Technique can be applied to both small simple 3D environments, as shown above, and to large detailed models such as that shown in figure 5.3, which shows a plan view of the 3D model of the German railway introduced in Chapter 4 (the black area located on the middle right of the image is a portion of the environment which was not included in the aerial survey). The location and direction of the critical viewpoint shown in figure 4.9 of chapter 4 has been highlighted in yellow on the image.

⁷⁸ Images by the author (January 2003).



Figure 5.3: Plan view of the German railway environment⁷⁹.



Figure 5.4: Rendered plan image with a single omni light positioned at selected viewpoint⁸⁰.

⁷⁹ Overhead view of a 3D model created by the author (February 2002).

⁸⁰ Image by the author (January 2003).

An omni light was placed at this critical viewpoint and all other lights in the environment were turned off. To distinguish dimly lit areas due to shadows and dark areas due to dull coloured objects, all objects were coloured white. The resulting rendered plan image is shown in figure 5.4.

Using Paint Shop Pro, the visible areas (represented by the light coloured regions) of figure 5.4 were coloured red and composited with the plan image of the environment to produce an FVI, which is shown in figure 5.5, which can be easily understood. As the image shows, the visible parts of the environment, shown in red, mainly match up with the edges of the buildings as would be expected.



Figure 5.5: FVI resulting from the viewpoint indicated by the yellow dot⁸¹.

To confirm that the FVI produced in figure 5.5 was accurate, a panoramic image was produced

⁸¹ Image by the author (January 2003).

from that viewpoint and this is shown in figure 5.6. The features which could or could not be seen from the FVI were compared with the panoramic image and it was concluded that they convey exactly the same information in respect to what can be seen from that viewpoint.



Figure 5.6: Panoramic view of German railway environment⁸².

5.2.2.2 Cumulative Reflective Field of Visual Influence

To produce a cumulative FVI, omni lights can be placed at a number of selected viewpoints in the virtual environment. The resulting rendered plan image will indicate dark areas which cannot be seen by any of the viewpoints and light areas which can be seen by at least one of the viewpoints. Figure 5.7 shows an example of a cumulative FVI produced using two omni lights positioned at two different locations in the 3D environment (as indicated by the two yellow markers). This method is not ideal since the FVI does not indicate which areas of the environment can be seen from each individual location.

In order to produce a cumulative FVI where it is possible to identify which areas can be seen from each viewpoint, a number of individual reflective FVI images can be combined together as separate layers and composited over a base image of the environment. Figure 5.8 shows two FVIs (one coloured blue and the other red), using the same viewpoints as in figure 5.7, that have been combined together in this fashion to produce a cumulative FVI which also shows its constituent individual FVIs.

⁸² Image by the author (January 2003).



Figure 5.7: Cumulative FVI produced using two omni lights simultaneously⁸³.



Figure 5.8: Cumulative FVI produced by combining two individual FVIs⁸⁴.

⁸³ Image by the author (January 2003).

⁸⁴ Image by the author (January 2003).

5.2.2.3 Projective Field of Visual Influence

Single projective FVIs are produced in almost the same way as single reflective FVIs. The only difference is that an omni light is placed at a point within the object's location (the object being the item to be assessed, for example a new development) and hence the light rays will delineate the extent of visibility of a point on the object to its surroundings.

Figure 5.9a shows the car used in the previous example with a yellow circular mark indicating a point on the car from which to perform a projective FVI. An omni light was placed at this point and using the same method as described above an FVI was produced which is shown in figure 5.9b. The blue shaded areas indicates areas which can see the selected point on the car, as indicated by the yellow marker.

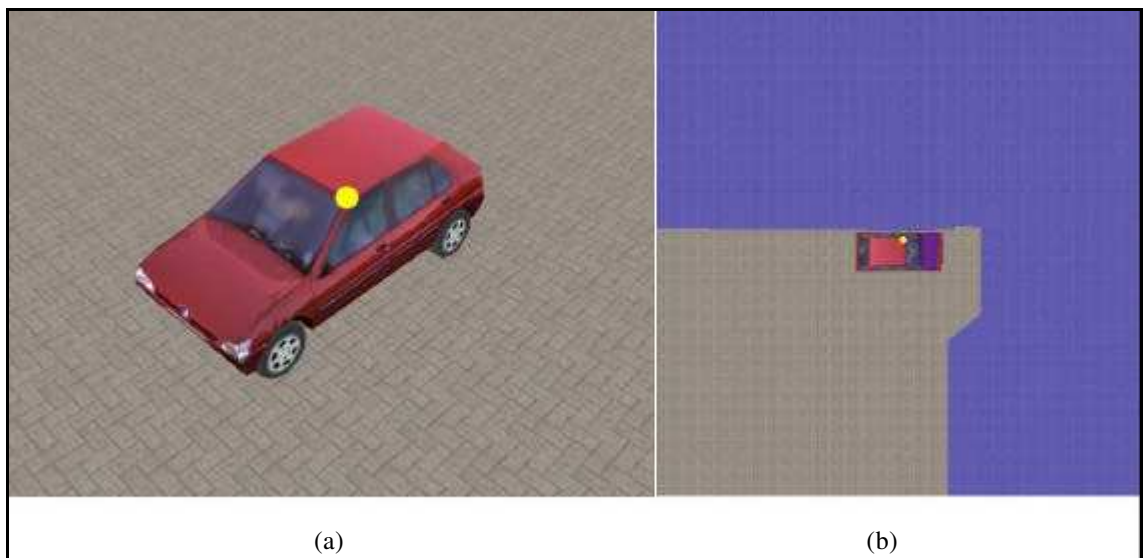


Figure 5.9: A projective FVI initiated from a point on the car shown by the yellow marker⁸⁵.

Projective FVIs of this nature may not be very useful for VIA since it is often necessary to assess the visibility of a whole development and not just a single point on the development. This can be achieved using cumulative projective FVIs.

⁸⁵ 3D model and image by the author (January 2003).

5.2.2.4 Cumulative Projective Field of Visual Influence

Cumulative projective FVIs are inherently difficult to produce since they involve assessing the visibility of multiple points on an object with relation to multiple points on the environment. The novel FVI technique described below assesses the visibility for a number of specified points by the placement of a number of omni lights.

Figure 5.10 shows a rendered view of one of the proposed railway structures within the German railway model, from which a projective FVI has been produced. The exterior of the virtual structure was covered in a number of omni lights (figure 5.11), with the only limit on the number of lights being due to the processing power of the computer. A projective FVI was produced and this is shown in figure 5.12 with the proposed railway structure highlighted in yellow and areas which can see the structure highlighted in red.



Figure 5.10: Rendered image of the proposed railway structure⁸⁶.

⁸⁶ 3D model created by the author (February 2002).

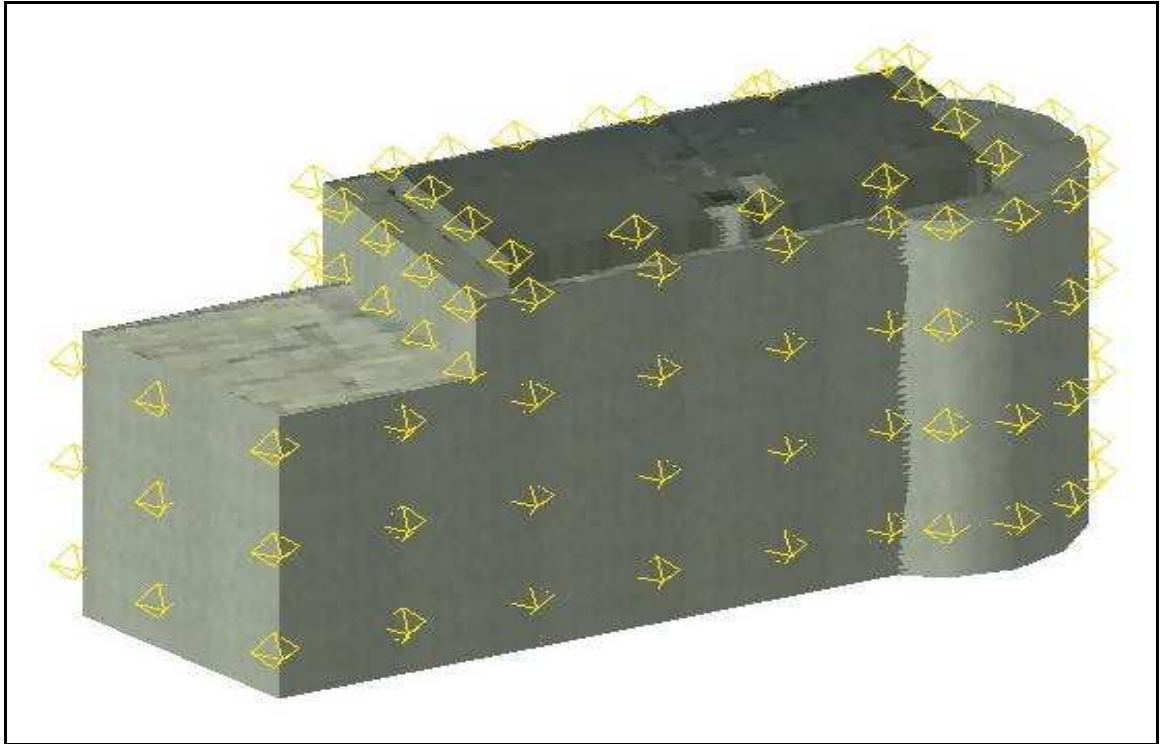


Figure 5.11: The positioning of omni lights to produce a projective FVI⁸⁷.



Figure 5.12: Projective FVI for the structure shown in yellow⁸⁸.

⁸⁷ Screenshot taken from 3D Studio MAX by the author (January 2003).

⁸⁸ Image by the author (January 2003).

5.2.3 Dene Quarry - Field of Visual Influence Example

A further example of the novel FVI technique is demonstrated by the following short project in which a simple cumulative projective FVI was required for a quarry called Dene Quarry. This quarry is situated near Cromford in Derbyshire and has been in operation since 1942 producing limestone. In depth information about the area was not available for modelling purposes since the client did not require a detailed FVI and therefore the CG model did not contain surface features, such as vegetation and buildings, and the effects of Earth curvature and atmospheric refraction were also ignored in this case.

Contour data was supplied in the form of a DEM which was imported into 3D Studio MAX. The contours were converted into a 3D mesh which was then textured using aerial photographs, taken from Multimap (2003), to produce the image shown in figure 5.13.



Figure 5.13: 3D model of Dene Quarry and surrounding environment⁸⁹.

⁸⁹ 3D model created by the author (July 2000).

To produce a cumulative projective FVI a number of omni lights were placed around the quarry boundaries, as shown in figure 5.14. The texture map was removed from the model and replaced with a simple white colour so that the dark areas of the texture map would not get confused with areas in shadow.



Figure 5.14: Placement of the omni lights around the quarry perimeter⁹⁰.

With all other lights turned off the plan view of the model was rendered and the resulting FVI was then manipulated using Paint Shop Pro to produce the image shown in figure 5.15. The FVI was then composited with an OS map of the area and mapped onto the 3D model to produce the 3D FVI model shown in figure 5.16, which enabled an easier understanding of the FVI.

⁹⁰ Image by the author (July 2000).

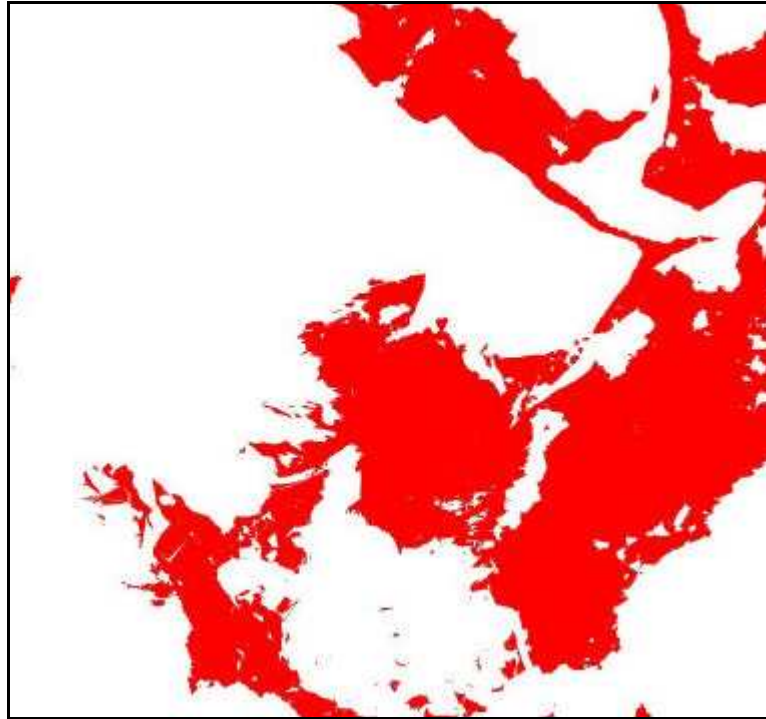


Figure 5.15: FVI for Dene Quarry⁹¹.

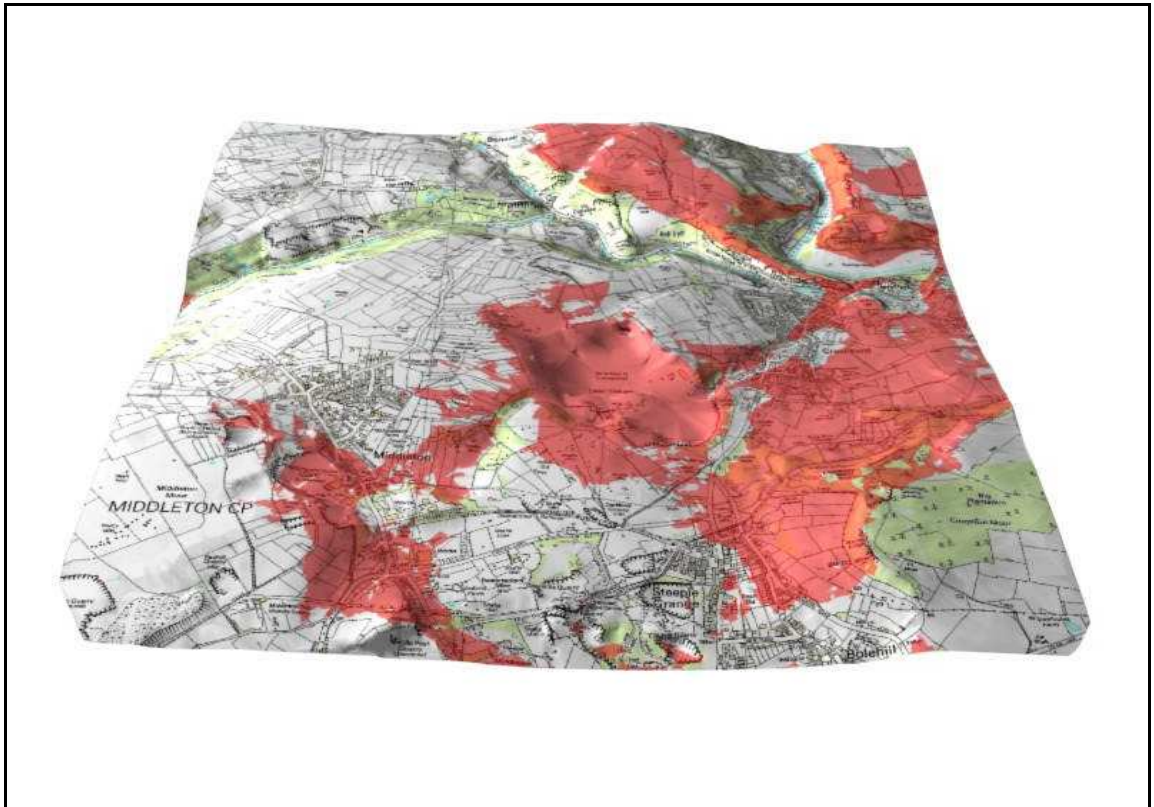


Figure 5.16: 3D FVI of Dene Quarry⁹².

⁹¹ Image by the author (July 2000).

⁹² Image from a 3D model created by the author (July 2000).

The 3D FVI determined that Dene Quarry produces very little visual impact on the surrounding residential areas. If surface features were taken into account then the visual impact resulting from the quarry would be much less since the many tree belts would provide screening from the quarry. The FVI also clearly shows that areas which can see the quarry are located on higher ground as would be expected.

5.2.4 Analysis

A simple technique has been developed which can quickly and accurately produce FVIs from 3D models using the concept of light and shadows. One advantage of this technique over existing techniques is that it does not require specialist FVI software since it is based upon using standard commercially available 3D modelling software packages.

The use of 3D modelling software packages also has the advantage of being able to accurately model surface features such as buildings and vegetation and can even accommodate for the semi-transparent nature of vegetative foliage with the use of opacity mapping techniques (described in detail in section 5.5). The technique can also account for the effects of Earth curvature and atmospheric refraction using software described later in this chapter.

The biggest disadvantage of this technique is with projective FVIs, since it may not be possible accurately produce FVIs for large scale complex developments since a significant number of lights will have to be placed on the development's exterior which would require a substantial amount of computer processing power and hence processing time.

One of the inherent problems with projective FVIs is that the FVI will only assess whether a development can be seen from either the ground surface or from structures which have been placed on the surface. For example, although a projective FVI may suggest that an area of land will not be able to see a proposed development, a person standing in that area might be able to

see the development since their eye height was not taken into account. This could be a major issue for developments which are situated near to public footpaths for example. A solution to this problem is to include representative models of people or blocks of people in areas of concern so that the omni lights will either illuminate or cast shadow on the people models giving a direct indication of whether they will see the development or not.

5.3 Percentage View Change Analysis

5.3.1 Introduction

Chapter 3 highlighted the need for a simple and accurate technique to calculate the percentage view and percentage view change of objects in an image, the data from which can be used to assess the visual impact of a proposed development or land use change. The technique described below is a novel CG technique developed by the author which uses a 3D model of an environment to produce an image which can easily be assessed for the percentage view taken up by particular objects in that view.

5.3.2 Methodology

The problem with current CG percentage view techniques is that they cannot always accurately and easily distinguish between different image features due to repeating colours in different features. For example, there is no current simple method to distinguish between two similar, but different, trees in an image. However, if the image could be modified by colouring each different feature a different colour then it would be easier to distinguish between features and hence perform a percent view analysis. Modifying the image in this way can also be a problem with current 2D CG techniques, but using a 3D CG model of the environment solves this problem since it is simple to change the colours of the various environment features.

Once a 3D CG model of the environment has been produced with different features coloured

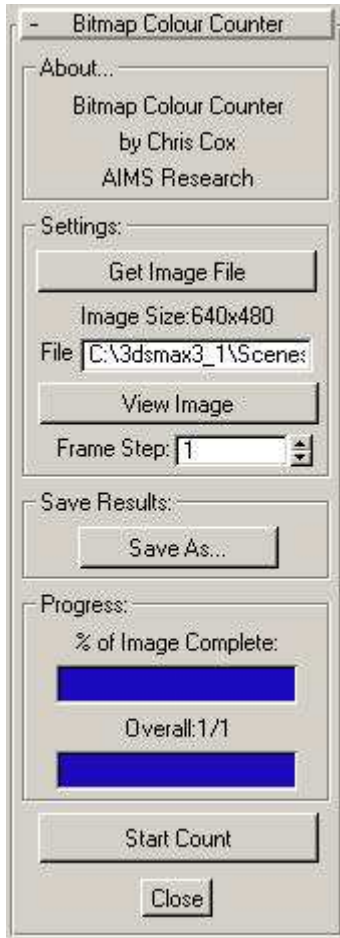


Figure 5.17: Bitmap Colour Counter interface⁹³.

uniquely, an image from the viewpoint location should be rendered. This image now needs to be analysed in order to determine the percentage view of each feature. To do this, a software utility called “Bitmap Colour Counter” was produced using 3D Studio MAX R3.1’s MAXScripting function (the MAXScript code for the utility can be found in appendix 5). Figure 5.17 shows the user interface of the utility.

The software utility works by analysing individual pixels within a bitmap image and sorting them into colour groups based upon their RGB values (table 5.2 details the colour groups and their respective RGB values in which the colours must lie). A delimited text file, which can be easily imported into a spreadsheet software package, is then produced which details the number and percentage of pixels within each

colour group. This information can then be used to determine the percentage of an image taken up by a particular colour and hence the percentage view of each feature.

Colour	RGB Settings		
	Red	Green	Blue
Red	≥ 128	< 128	< 128
Green	< 128	≥ 128	< 128
Blue	< 128	< 128	≥ 128
Cyan	< 128	≥ 128	≥ 128
Yellow	≥ 128	≥ 128	< 128
Magenta	≥ 128	< 128	≥ 128
Black	< 128	< 128	< 128
White	≥ 128	≥ 128	≥ 128

Table 5.2: RGB limits of the eight colour groups accepted by the Bitmap Colour Counter.

⁹³ Image captured from software created by the author (November 2002).

Figure 5.18 shows a simplified flowchart of the process required to produce a percentage view change calculation from a selected viewpoint within a 3D CG model. Since there are eight colour categories, the user may assess the percentage view of up to eight different features by giving each different feature a different unique colour as specified by table 5.2. For example, vegetation could be coloured green, the ground red and a new development blue.

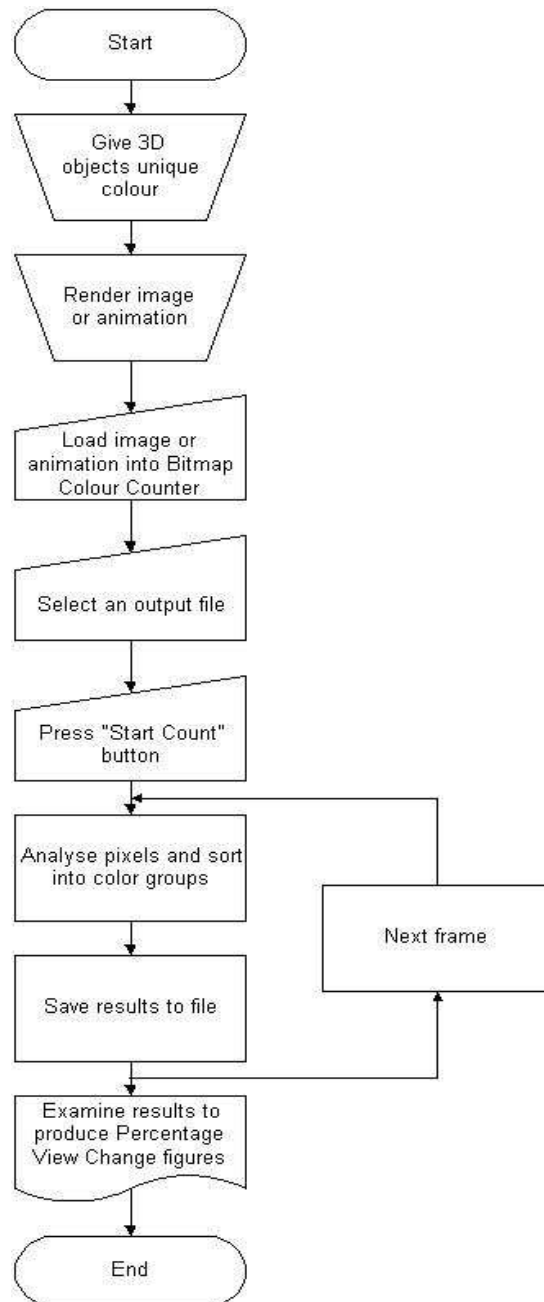


Figure 5.18: Flowchart of the percentage view change technique⁹⁴.

⁹⁴ Flowchart by the author (November 2002).

The view should then be rendered, either as a single image or an animation, and saved to disk for it to then be opened in the Bitmap Colour Counter. Although the rendered image can be of any size and aspect ratio, the author has used a fixed aspect ratio for all percentage view analyses that have been performed in this thesis. The aspect ratio is important since the results from this computerised percentage view change technique vary according to the ratio used. Therefore, for consistency between obtained results, a fixed aspect ratio has been defined as four to three (four units horizontally to three units vertically, hereafter referred to as 4:3), which is the common aspect ratio for computer monitors and televisions. Further research could be undertaken to determine the correct aspect ratio that should be used that ties in with the human field of vision. Chapter 8 discusses this potential further research in more detail.

The user must then select where to save the results before pressing the “Start Count” button. The utility will assess each pixel in the image or, if an animation was loaded, it will assess each pixel in every frame (or every nth frame as specified by the user).

The number of pixels and percentage of each colour group is saved to file in a delimited text format which means that it can be easily converted into a spreadsheet format for assessing the results. Comparing output produced from a viewpoint showing pre-development and the same viewpoint showing after or during development will result in the percentage view change for various features. Figure 5.19 shows an example text file which is produced by the utility and figure 5.20 shows an example of the output that has been opened into a spreadsheet application.

There are a number of factors which should be taken into account when producing an image from a 3D CG modelling application since the accuracy of the results could be affected. Table 5.3 lists these factors and a brief explanation behind each issue.

```

Bitmap Colour Counter  by Chris Cox
Image: C:\3dsmax3_1\Scenes\German Railway\Panorama\Image01.bmp
Resolution: 640 by 480
Total Pixels: 307200

Frame,Red Pixels,Percentage Red,Green Pixels,Percentage Green,Blue Pixels,Percentage Blue,Cyan
Pixels,Percentage Cyan,Yellow Pixels,Percentage Yellow,Magenta Pixels,Percentage Magenta,Black
Pixels,Percentage Black,White Pixels,Percentage White
0,1146,0.373047,7151,2.3278,68810,22.3991,23897,7.77897,2892,0.941406,0,0.0,170385,55.4639,32919,10.7158

```

Figure 5.19: Example text file output from the Bitmap Colour Counter⁹⁵.

Bitmap Colour Counter by Chris Cox						
Image: C:\3dsmax3_1\Scenes\German Railway\Panorama\Image01.bmp						
Resolution: 640 by 480						
Total Pixels: 307200						
Frame	Red Pixels	Percentage Red	Green Pixels	Percentage Green	Blue Pixels	Percentage Blue
0	1146	0.373047	7151	2.3278	68810	22.3991

Figure 5.20: Example spreadsheet output from a Bitmap Colour Counter text file⁹⁶.

Settings	Factor	Reason
Material	Self-illumination must be applied to all models.	Prevents shadows and light attenuation, hence preventing colour alteration.
	Opacity maps must be pure black and white.	Stops semi-transparent objects mixing colour with objects situated directly behind.
Environment	Lights should be turned off.	Prevents colour alteration.
	Environmental effects off.	Prevents colour alteration.
Rendering	Images should be rendered at a high resolution.	Provides sharper edges.
	Anti-aliasing must be turned off.	Prevents edge blurring.
	Filter maps must be turned off.	Prevents edge blurring.
	Images and animations should not be compressed.	Prevents blurring and colour alteration.

Table 5.3: Factors to consider when producing an image from a 3D CG modelling application.

⁹⁵ Image of the text file created by the author (November 2002).

⁹⁶ Spreadsheet created by the author (November 2002).

Figure 5.21 shows an image rendered from a viewpoint within a CG 3D environment. In order to determine the percentage of view of the various features shown in the image the 3D environment was modified so that the trees were given a red colour, the buildings yellow, the ground green, the car blue and the sky black. The viewpoint was then rendered again at a resolution of 800 by 400 pixels following the guidelines set out in table 5.3 and is shown in figure 5.22.



Figure 5.21: Rendered image from the original 3D environment⁹⁷.

The modified image was loaded into the Bitmap Colour Counter and processed with the results being saved as a delimited text file. The text file was then imported into a spreadsheet application and formatted to produce the table shown in table 5.4. The table shows the percentage view of each of the five selected features. If the 3D environment is changed, for example by adding more vegetation, and a new image produced, the data obtained from the new

⁹⁷ Image from a 3D model created by the author (January 2003).

image can be compared with the original data to determine the percentage view change of the various features. This is illustrated in more detail in the case study below.

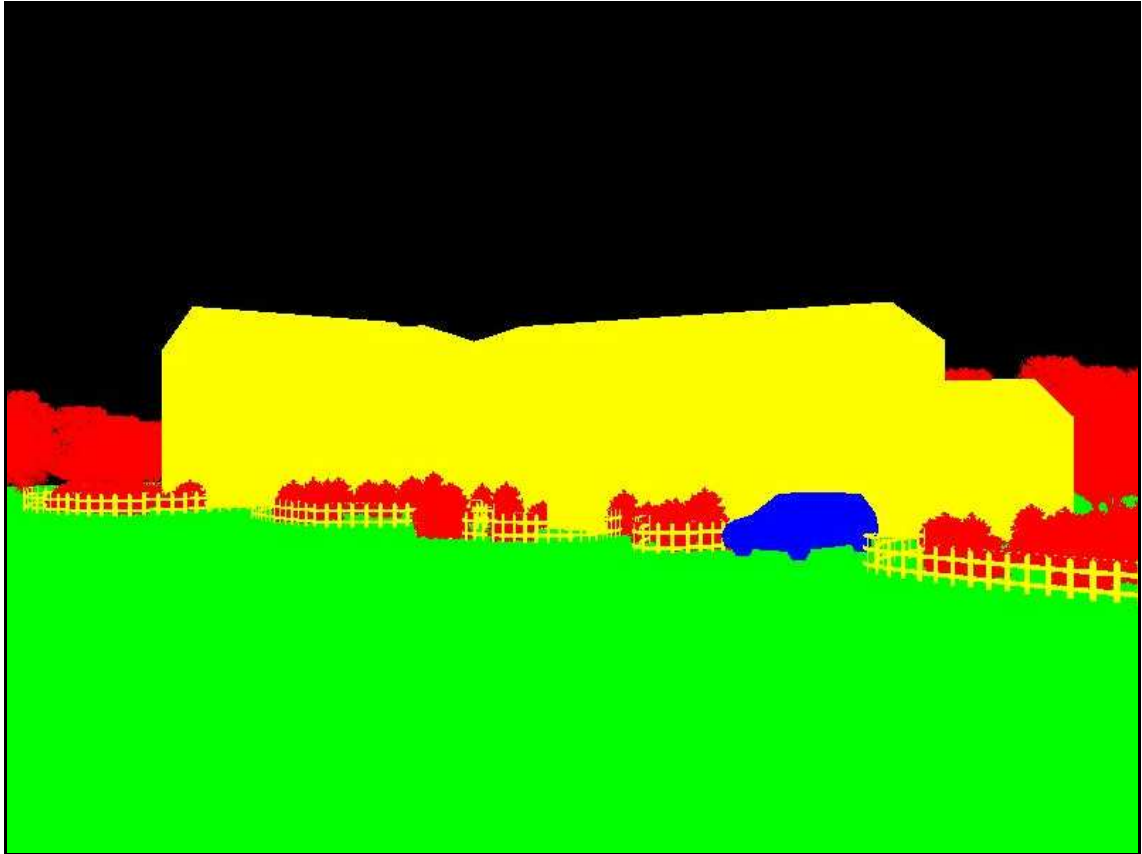


Figure 5.22: Rendered image from the modified 3D CG environment⁹⁸.

Colour	Feature	Pixels	%
Red	Vegetation	24680	5.14
Green	Ground	175900	36.65
Blue	Car	3778	0.79
Yellow	Buildings	86086	17.93
Black	Sky	189556	39.49
Total		480000	100.00

Table 5.4: Percentage view results for figure 5.22.

⁹⁸ Image from a 3D model created by the author (January 2003).

5.3.3 Road Sign Visibility Example

Following a discussion with the Transport Research Laboratory (2002) it was decided to build an example 3D CG environment which showed how the placement of road signs could be assessed to determine their visibility to oncoming drivers. This method could then possibly be used by the Transport Research Laboratory for future Highway Planning Audits which they are required to perform for all new roads.

Figure 5.23 shows a rendered image of a view from the example 3D CG model which was produced on behalf of the Transport Research Laboratory. The image shows a white car coming up to a sharp left turn with a red car approximately 12 meters behind it. Figure 5.24 shows an image representing the red car's driver view. The road signs indicating that a left turn is approaching are partially hidden by the car ahead and a tree to the left. Figure 5.25 shows the same view but with the road signs moved so that they are more visible to oncoming drivers.



Figure 5.23: Rendered image of the road sign visibility 3D CG model⁹⁹.

⁹⁹ Image of a 3D model created by the author (July 2002).



Figure 5.24: Poor visibility of the road signs¹⁰⁰.



Figure 5.25: Good visibility of the road signs¹⁰¹.

¹⁰⁰ Image of a 3D model created by the author (July 2002).

¹⁰¹ Image from a 3D model created by the author (July 2002).

To calculate the percentage view of the road signs for both the poor and good visibility scenarios, the road signs were coloured red within the 3D CG model and all other objects were turned black. The two views were then rendered with an aspect ratio of 4:3 and at a resolution of 800 by 600 (figure 5.26), loaded into the Bitmap Colour Counter and the results saved. The two text files were opened into a spreadsheet and the percentage view change of the road signs determined (table 5.5). The percentage view change in road sign visibility between the poor and good visibility scenarios equates to an 897 percent increase of view.

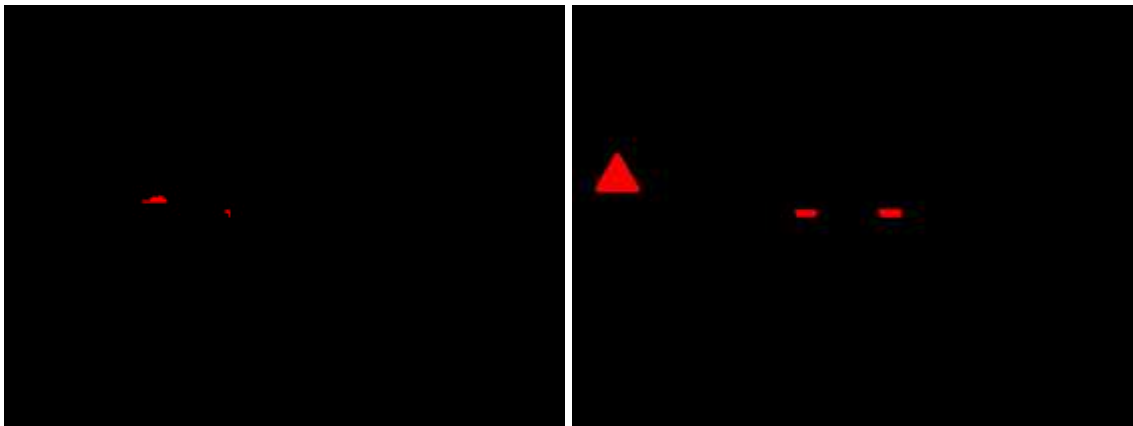


Figure 5.26: Modified images of the poor (left) and good (right) visibility scenario viewpoints¹⁰².

	Red Pixels	% Red	Black Pixels	% Black
Before	286	0.06	479714	99.94
After	2801	0.58	477199	99.42
Change	2515	0.52	-2515	-0.52

Table 5.5: Percentage view change between before (poor visibility) and after (good visibility) scenarios.

5.3.4 Analysis

A software utility has been produced, called Bitmap Colour Counter, which determines the percentages of eight different colour groups within a bitmap image. Used alongside a 3D CG model, the percentage view of various objects may be determined from a selected viewpoint and hence percentage view change calculations may be made.

¹⁰² Images from a 3D model created by the author (July 2002).

The novel percentage view change technique was shown to experts and peers at the Ninth International Conference on The Modelling, Monitoring and Management of Environmental Problems in Bergen, Norway (Cox and Schofield, 2002). There was a very positive feedback from the audience, with typical comments including:

“...the technique will change the future of environmental planning...”

“...could be very useful in my work situation...”

“...a new way to approach a traditional problem...”

The new technique is very accurate so long as the 3D model, which is used to create the rendered image used by the utility, is a faithful representation of the environment being modelled. This technique can also assess the percentage view changes which may occur over time or as the viewing location changes by analysing each frame in an animation. This can be useful, for example, to assess the change in view of a proposed building due to vegetative screening changing over time, or the change in view from various points along a public footpath overlooking a proposed development.

The disadvantages with this technique is that care must be taken to produce an image which is made up of clear distinguishable colours so that the Bitmap Colour Counter utility can count the number of pixels within a colour group correctly. The factors required to produce such an image have been clearly outlined in table 5.3.

5.4 Earth Curvature and Atmospheric Refraction

5.4.1 Introduction

Chapter 3 showed that if the effects of Earth curvature and atmospheric refraction were not taken into account when performing a VIA for large scale projects then inaccuracies may occur. Therefore, it was decided to develop software to modify 3D CG landscape surfaces so that they will account for elevation loss due to the effects of Earth curvature and atmospheric refraction.

The software had to be simple to use and take into account the change of the refraction and curvature coefficient at different altitudes.

MAXScripting was used to produce a landscape curving utility, called “Earth Curver”, which runs within 3D Studio MAX. A detailed description of the utility is given below and the MAXScripting code can be found in appendix 6.

5.4.2 Methodology

The Earth Curver utility will automatically curve a selected surface within 3D Studio MAX by measuring the horizontal distance of each vertex of that surface from a point of reference and moving them down by an amount derived from the equations shown in figure 3.19 in chapter 3. Figure 5.27 shows a screenshot of the command interface of the Earth Curver utility. To function correctly the user must first specify the current system units being used by the modelling software since the equations used by the model are unit dependant. The approximate real world altitude of the surface being modelled must also be specified since the equations take into account the refraction and curvature coefficients which depend upon altitude.

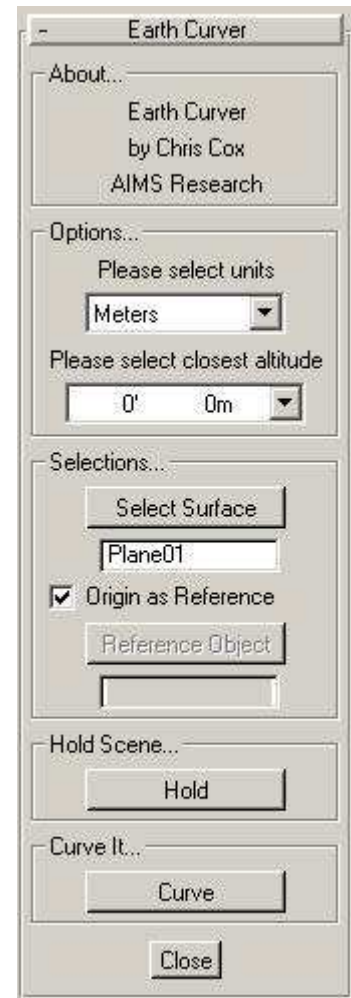


Figure 5.27: The Earth Curver interface¹⁰³.

The required surface is then selected and the user has an option to choose an object to act as a reference point from which all calculations are then based. If no reference point is chosen then the world origin is assumed to be the reference point. The user also has the choice of

¹⁰³ Image captured from software created by the author (November 2002).

temporarily saving the scene (also known as holding) before curving the landscape since changes cannot be reversed.

In order for the utility to function correctly the selected surface must be an editable mesh (defined as a model which can be manipulated as a triangular mesh object at vertex, edge and face levels). If the surface is not an editable mesh then it is converted into one before proceeding. Each vertex of a landscape mesh is moved vertically down by an amount determined by the equation which was shown in figure 3.19. Figure 5.28a shows a wireframe surface which has not been curved whilst figure 5.28b shows the same surface with curvature applied (exaggerated for illustration purposes).

The equation requires the determination of the coefficient of refraction and curvature, and the planar distance between the vertex and the reference point. The coefficient of refraction and curvature is determined based upon the altitude the user has selected. The planar distance is determined by measuring the x and y values (based on a horizontal plane) between the vertex points and reference point and using Pythagoras' theorem to calculate the planar distance. The equation must also be altered, according to the units used by the modelling software, before proceeding with the elevation loss calculation.

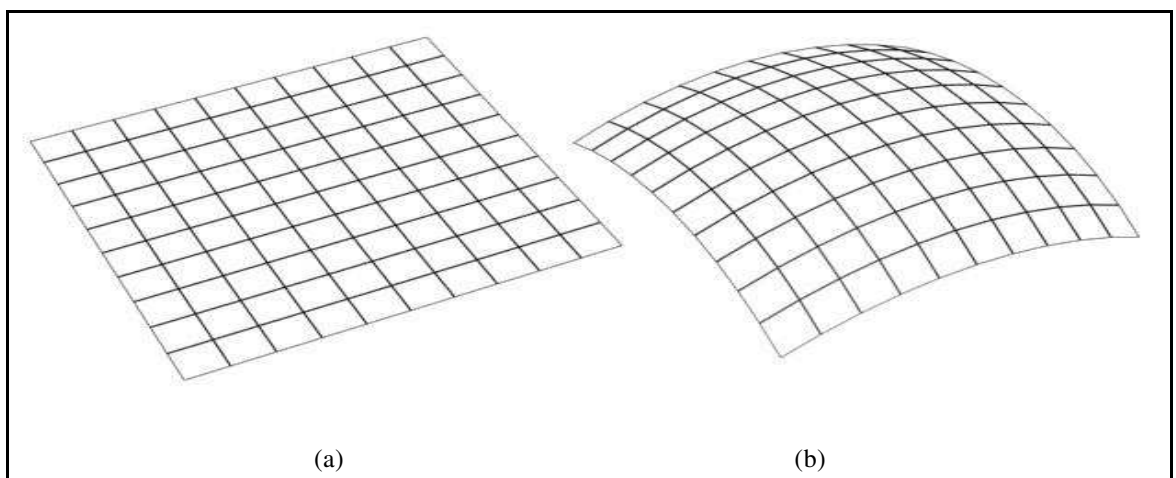


Figure 5.28: Original surface (a) and the curved surface (b) (surface curvature has been exaggerated for illustration purposes)¹⁰⁴.

¹⁰⁴ Images by the author (December 2002).



Figure 5.29: View of proposed development before ground has been curved¹⁰⁵.

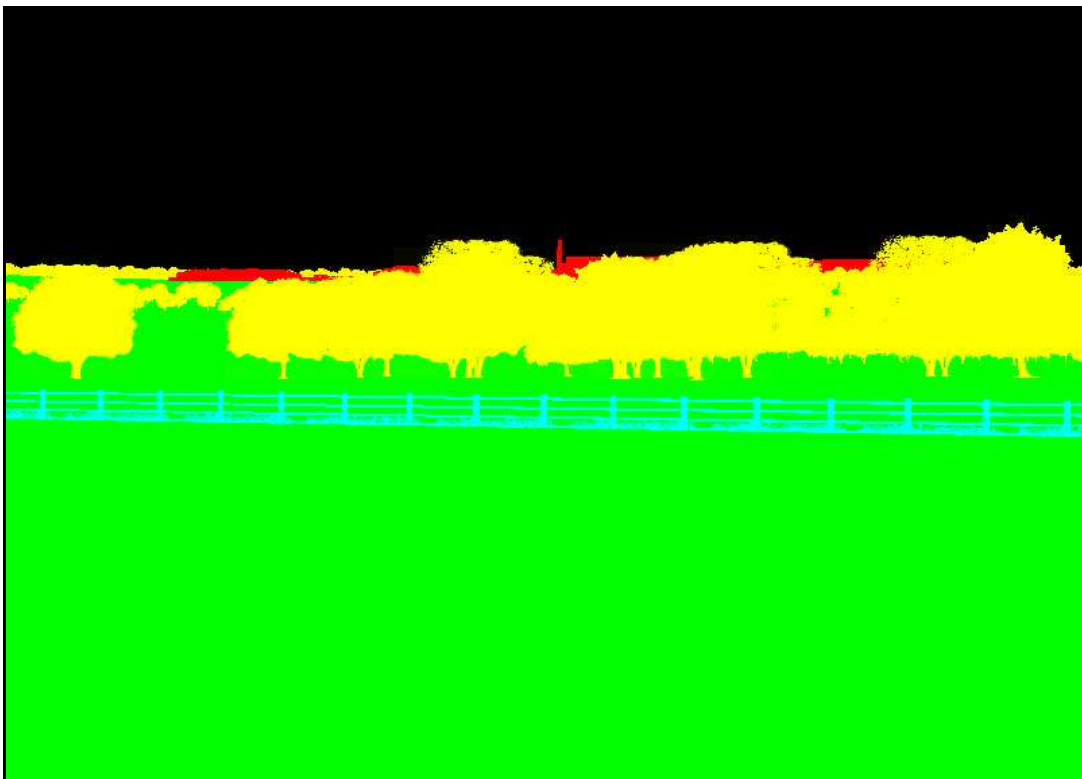


Figure 5.30: Modified view of proposed development before ground has been curved¹⁰⁶.

¹⁰⁵ Image from a 3D model created by the author (January 2003).

¹⁰⁶ Image from a 3D model created by the author (January 2003).

Figure 5.29 shows an image of an example 3D CG scene, viewed from a house looking towards a proposed development situated approximately 4 kilometres away. With disregard for the effects of Earth curvature and atmospheric refraction the view was modified so that it could be assessed using the Bitmap Colour Counter to determine the percentage view of the development. The trees were coloured yellow, the ground green, the development red, the fence cyan and the sky black (figure 5.30). The image was rendered, processed by the Bitmap Colour Counter and the results were saved as a delimited text file.

The ground surface of the original 3D model was then curved using the Earth Curver software utility using the viewpoint location as a reference point. All the surface features were moved vertically down as applicable to meet up with the surface and at a distance of 4 kilometres the proposed development had to be moved vertically down by 1.08 metres. Again the 3D model was colour modified and the viewpoint rendered. The rendered image was then analysed by the Bitmap Colour Counter and the results saved to file.

The two files were opened into a spreadsheet package and table 5.6 was produced from the results. The results show that there was a 0.05% decrease in view of the development due to the effects of Earth curvature and atmospheric refraction.

	% Development (red)	% Ground (Green)	% Fence (Cyan)	% Trees (Yellow)	% Sky (Black)
No Curvature	0.37	53.25	2.04	12.34	32.01
With Curvature	0.32	53.20	2.03	12.35	32.10
Change	-0.05	-0.05	-0.01	0.01	0.09

Table 5.6: Percentage view change of various features.

5.4.3 Analysis

A MAXScript utility, called Earth Curver, has been developed which will curve a landscape within 3D Studio MAX to account for the elevation loss due to Earth curvature and atmospheric refraction. The utility is a very important tool for large scale developments since Earth curvature and atmospheric refraction may play an important part in the outcome of a VIA.

For a distance of 1 kilometre, the elevation loss is only approximately 7 centimetres, but for a distance of 5 kilometres the elevation loss is approximately 1.7 meters. This could mean that a proposed development which is 5 kilometres from a selected viewpoint would effectively be 1.7 meters lower than expected if the elevation loss was not taken into account.

The example 3D CG scene, which has been modelled in order to demonstrate the effect of Earth curvature and atmospheric refraction, shows a 0.05 percentage view decrease of the proposed development, due to an elevation loss of 1.08 metres. This low value was expected since the development occupies only a small proportion of the view from the house. For some developments a small change like this can decide upon the outcome of a VIA.

Although this utility accounts for the approximate altitude of a surface, it assumes a temperature of 18.3°C for its calculations. Generally for UK conditions this is acceptable, but for other differing climates the utility's equation must be altered accordingly. The accuracy of this utility also depends upon the number of vertices of the surface mesh. The higher number of vertices will lead to a more accurately curved surface, while a surface with a low number of vertices will not be as accurate.

5.5 Seasonal Variation and Growth of Vegetation

5.5.1 Introduction

The effects of seasonal variation and growth of vegetation are occasionally overlooked when assessing the visual impact of a proposed development. The screening effect of vegetation changes dramatically through the seasons and as vegetation grows through the years. Therefore a CG technique to assess the effects of seasonal variation and vegetative growth was required which was simple but effective.

The Percentage View technique described earlier in this chapter was used to determine the change in view, due to seasonal variations and tree growth, of an example environment modelled using 3D Studio MAX R3.1. The technique used is described in detail below.

5.5.2 Methodology

To assess changes in view due to the seasonal variation effect on vegetation, different bitmaps can be mapped on to 3D CG vegetation models to simulate different seasons. Figure 5.31 shows two different bitmaps for the same tree, the image on the left represents the tree in summer and the image on the right represents the tree in winter.

Each different vegetation bitmap requires its own opacity bitmap so that the vegetation model only shows the actual vegetation image and not the surrounding colour. Figure 5.32 shows the opacity maps which correspond to the images shown in figure 5.31. Black areas indicate transparent areas and white areas indicate that it should be rendered opaque. Figure 5.33 shows the difference between a 3D model of a tree with both a tree texture and opacity map applied and a tree model with just the tree texture applied. The black areas of the opacity map have prevented the magenta colour of the tree texture from being rendered in the image.



Figure 5.31: Summer tree bitmap (left) and a winter tree bitmap¹⁰⁷.

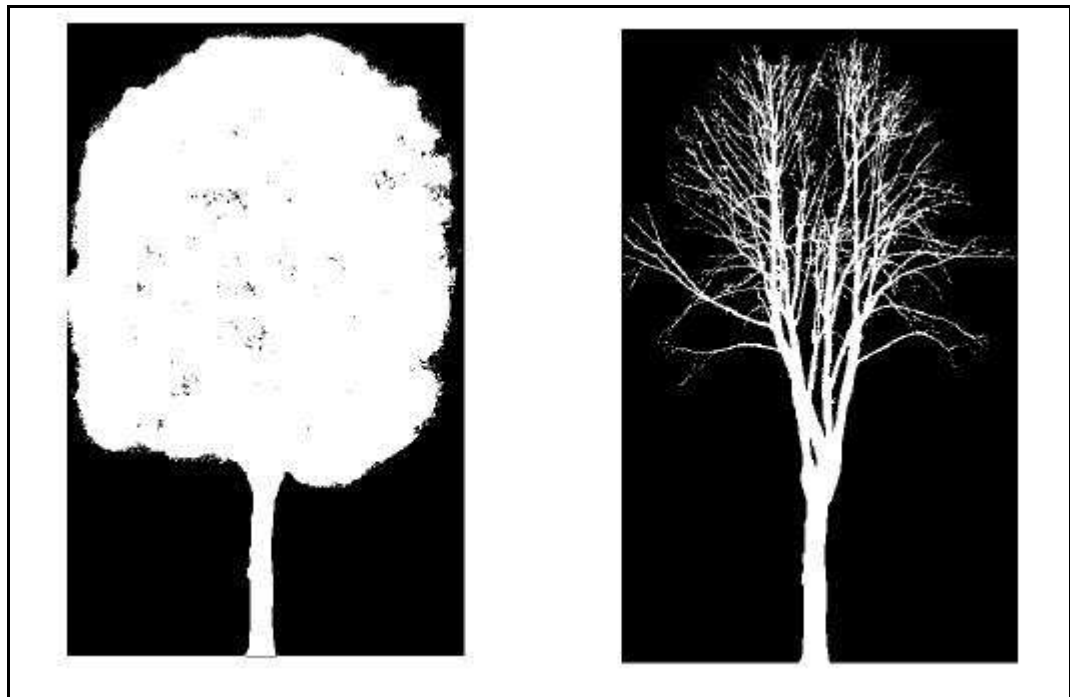


Figure 5.32: Summer tree opacity bitmap (left) and the winter tree opacity bitmap (right)¹⁰⁸.

¹⁰⁷ Images adapted from photographs taken by the author (November 2002).

¹⁰⁸ Images by the author (November 2002).

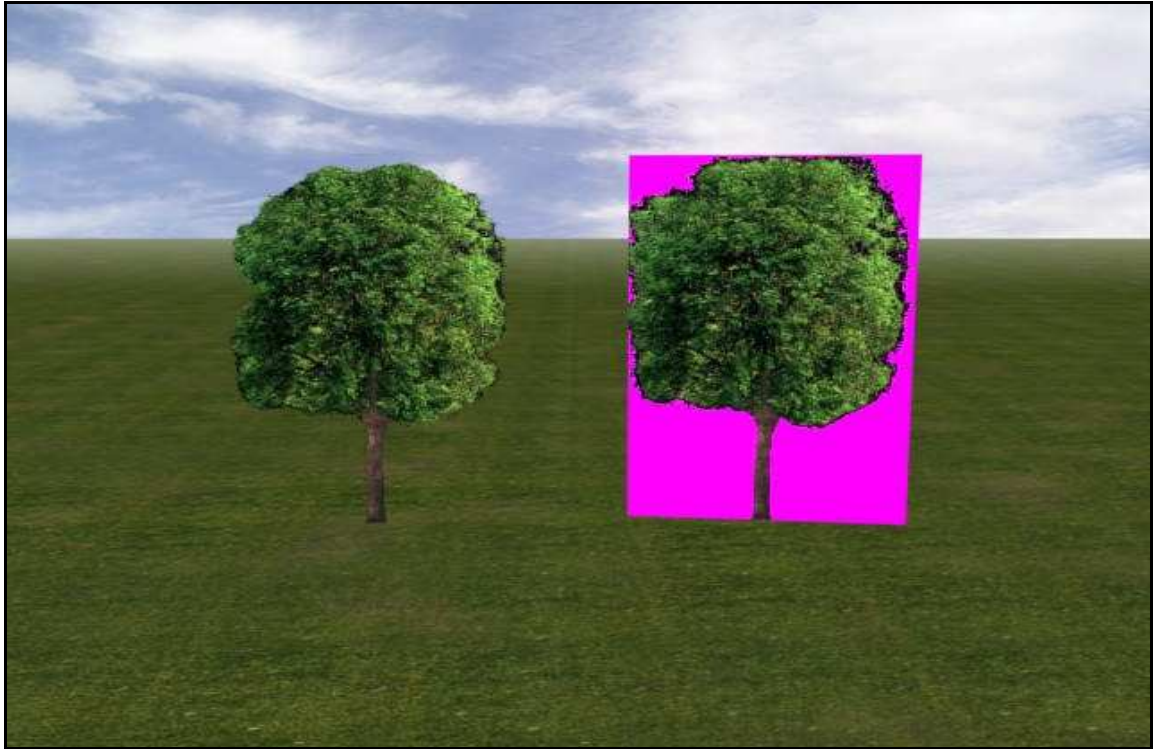


Figure 5.33: Tree model with opacity map (left) and tree model with no opacity map (right)¹⁰⁹.



Figure 5.34: Farmhouse overlooking proposed development¹¹⁰.

¹⁰⁹ Image rendered from a 3D model by the author (November 2002).

¹¹⁰ Rendered image from a 3D model created by the author (November 2002).

Figure 5.34 shows a rendered image of a farmhouse which overlooks a proposed development partially screened by a proposed tree belt. Example summer and winter 3D CG models were modelled with the summer model consisting of trees with full leaf cover and a field in crop whilst the winter model had bare trees and no crops in the field. To portray the different climates, the summer model was brightly lit and cloud cover was sparse whilst the winter model was dull and cloud cover dense. Viewpoints from the farmhouse bedroom window were then rendered for each model. The winter view, shown in figure 5.36, clearly shows a larger view of the proposed development than the summer view, shown in figure 5.35.

The increase in the area of the view taken up by the development can be calculated using the percentage view change technique described earlier in the chapter. For both summer and winter models, the tree belt was given a pure green colour and the new development a pure red colour. All other objects in the model were given a pure black colour. Images of the summer and winter view were then rendered from the same viewpoint, with an aspect ratio of 4:3 and at a resolution of 800 by 600, and are shown in figures 5.37a and 5.37b.

Both images were passed through the Bitmap Colour Counter, as previously described in section 5.3, and the results opened into a spreadsheet application where the percentage change in view of the development was calculated. Table 5.7 shows the percentage views of the proposed development and tree belt.

A 2.94% increase in the view of the development was determined during the winter season, mainly due to the decrease in view of the tree belt from 11.15% to 6.01%. It was also found that the crop in the field between the farmhouse and the proposed development also played a small part in screening the new development during the summer.



Figure 5.35: Summer view of proposed development¹¹¹.



Figure 5.36: Winter view of proposed development¹¹².

¹¹¹ Rendered image from a 3D model created by the author (November 2002).

¹¹² Rendered image from a 3D model created by the author (November 2002).

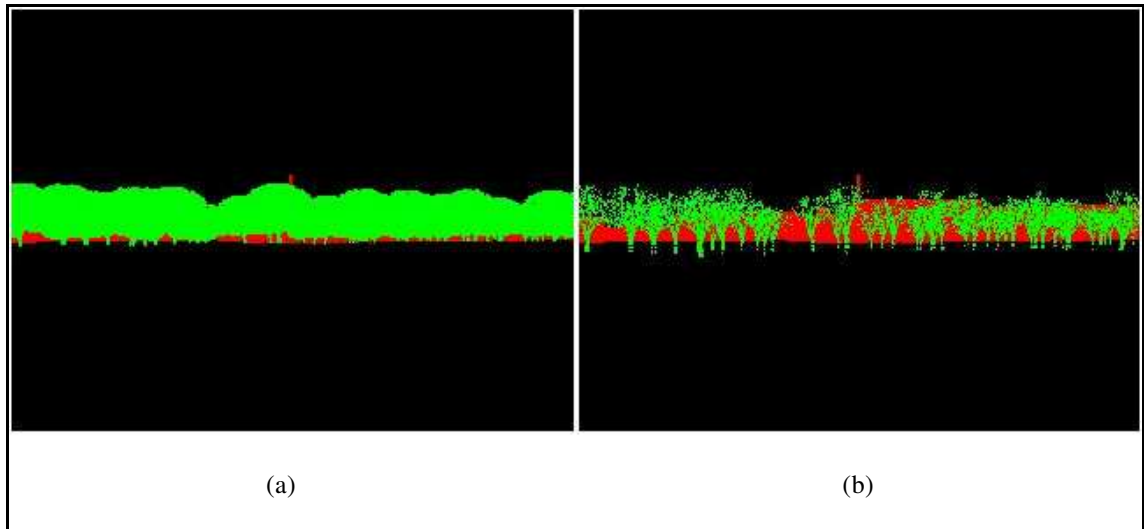


Figure 5.37: Summer (a) and winter (b) images from the Bitmap Colour Counter utility¹¹³.

	% view of new development (Red)	% view of tree belt Green	% view of other features (Black)
Winter	3.79	6.01	90.20
Summer	0.86	11.15	88.00
Change	2.94	-5.14	2.20

Table 5.7: Percentage view change of various viewpoint features.

To assess the effects of vegetative growth on screening a development, the summer model, applied above, was used to determine the change in view of the proposed development due to the growth of the tree belt from sapling to fully grown tree.

The trees were animated from a height of 1m and a width of 0.75m to a height and width of 10m over a 300 frame period which was taken to represent a 30 year period. Although tree growth data is available for specific varieties on projects, the growth rate was estimated since this example is meant only as a demonstration of the technique and not a case study.

As before, the tree belt was given a green colour, the new development given a red colour and

¹¹³ Images from a 3D model created by the author (November 2002).

every other feature a black colour. The animation was then rendered over the 300 frame time period. The Bitmap Colour Counter was then used to assess the animation using a frame interval of 10 in order to obtain results for each of the 30 years. Table 5.8 shows a summary of the obtained results.

Year	Frame	% view of tree belt	% view of new development
0	0	1.41	6.87
3	30	2.37	5.94
6	60	3.40	4.87
9	90	4.45	3.81
12	120	5.49	2.89
15	150	6.49	2.12
18	180	7.48	1.51
21	210	8.46	1.08
24	240	9.45	0.83
27	270	10.42	0.79
30	300	11.42	0.87

Table 5.8: Percentage view of tree belt and development every 3 years from initial planting.

The results show a clear decrease in the percentage view of the proposed development since the tree belt was planted and accordingly an increase in the percentage view of the tree belt.

5.5.3 Analysis

Using CG 3D modelling techniques and the Bitmap Colour Counter utility, which was discussed earlier, it is possible to quantitatively assess the change in visual impact due to seasonal variation and vegetative growth over time. An example model has been produced to demonstrate this technique.

The results gained from this technique can be used during the design stages of a development proposal to effectively plan vegetative planting so that the development will be screened from sensitive areas throughout the seasons. This technique, when used in conjunction with known

vegetative growth rate data, is also useful to evaluate when minimum and maximum screening may occur so as to develop a strategic planting scheme in order to minimise the visual impact of the development.

For accurate results, this technique relies upon accurate modelling data and realistic vegetative texture maps. Ideally, for existing vegetative screening, photographs of the vegetation should be used as texture maps for the 3D model. For proposed screening, photographs of the proposed vegetative species should be used. Also, when assessing the change in visual impact due to vegetative growth, photographs of the vegetative species at various ages should be taken and used as texture maps.

5.6 Virtual Reality Techniques

5.6.1 Introduction

The use of VR in VIA is fairly common at this present time and three other VR examples have been discussed previously in chapter 4. Currently VR simulations are mainly used to help visualise proposed projects in real-time and can often present different scenarios to the user, for example, what would the development look like if vegetative screening was planted.

However, VR can potentially offer much more than just a real-time 3D visualisation tool. Two novel VR approaches are discussed below which bring together different forms of VIA techniques, such as photomontages, FVIs, animations and percentage view change analysis, into integrated VR simulations. The first approach, using Safe-VR, was the first attempt of an integrated VR simulation, whilst the second approach, using Macromedia Director Shockwave Studio, improves upon the first adding more features and a simpler graphical user interface.

5.6.2 An Integrated Approach Using Safe-VR

5.6.2.1 Methodology

The VR environments were modelled using 3D Studio MAX 3.1 and exported as DirectX files which were then imported into Safe-VR. To keep the movement within the VR simulations smooth, the number of polygons were kept to a minimum by removing hidden and unnecessary faces and the number and size of texture bitmaps were also kept to a minimum where possible.

Figure 5.38 shows a screenshot from a Dene Quarry Safe-VR simulation before quarrying had started. The user is able to freely navigate around the environment and can switch between before, during and after quarrying models (figure 5.39). Using keyboard shortcuts, photographs and photomontages can be shown from critical viewpoints and will also serve to validate the accuracy of a VR model.

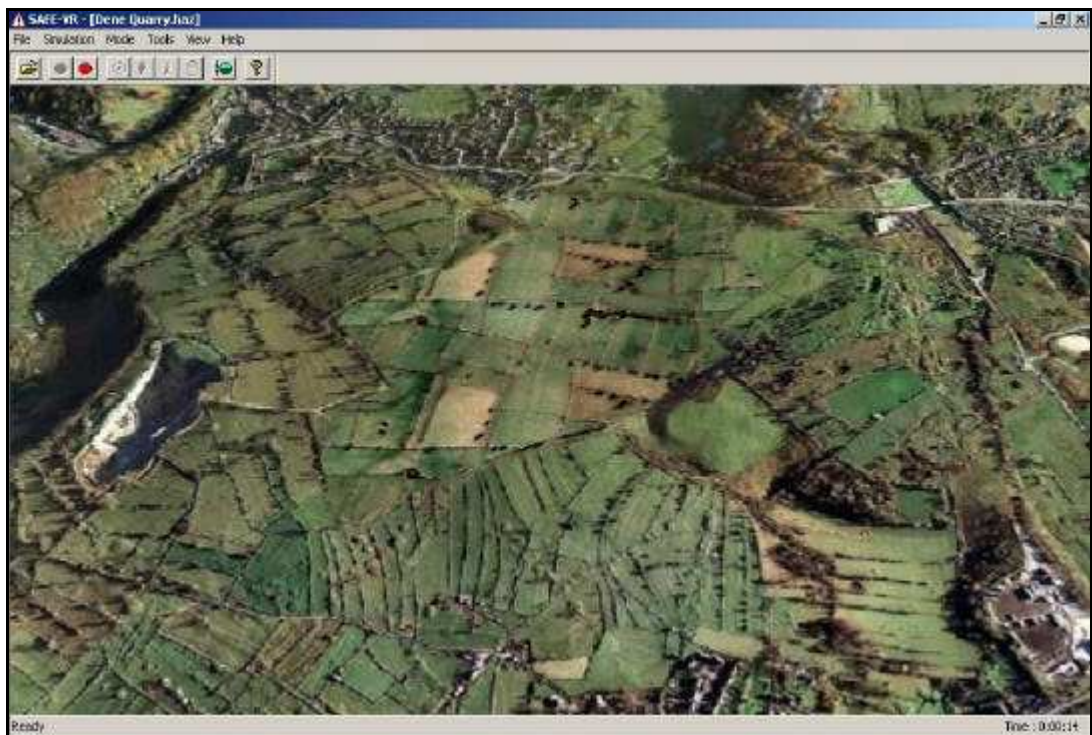


Figure 5.38: Dene Quarry environment before quarrying¹¹⁴.

¹¹⁴ Screenshot and 3D model by the author (July 2002).

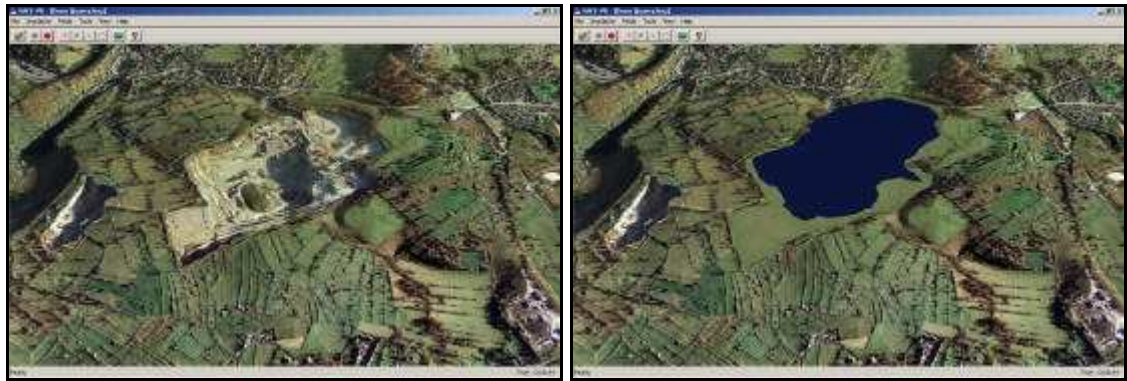


Figure 5.39: Dene Quarry environment during (left) and after (right) quarrying¹¹⁵.

FVIs, which were created using the technique described earlier, can also be shown as either an image within the VR world, or the ground texture map of a VR world can be replaced with an FVI from a critical viewpoint (figure 5.40).

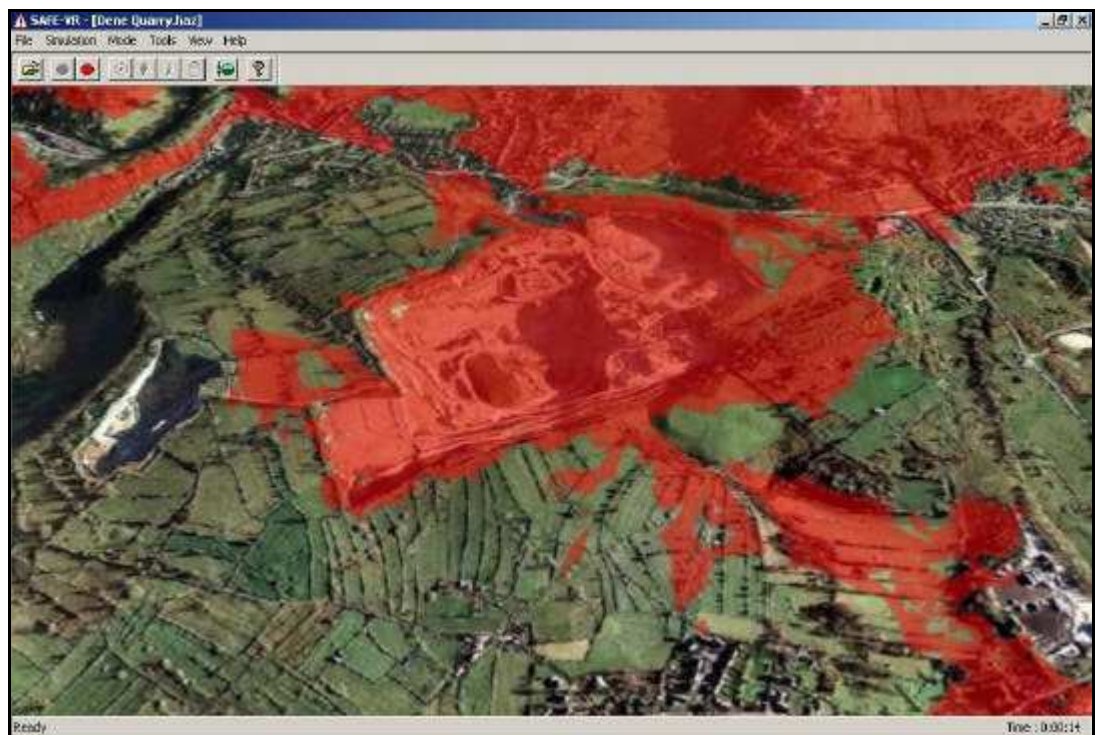


Figure 5.40: FVI draped over the 3D terrain surface¹¹⁶.

¹¹⁵ Screenshots and 3D models by the author (July 2002).

¹¹⁶ Screenshot and 3D model by the author (July 2002).

Percentage view calculations, which have been pre-determined using the Bitmap Colour Counter within 3D Studio MAX, can be graphically displayed within a VR simulation by either projecting them onto the sides of buildings from which they were produced (figure 5.41) or by simply showing a graph of results from a critical viewpoint.



Figure 5.41: Percentage view change results superimposed over house windows¹¹⁷.

5.6.2.2 Analysis

Safe-VR has been used to display various types of visual impact information within single VR simulations and the types of VIA techniques which can be integrated within a VR simulation are unlimited. A VR simulation of this type can be an extremely effective way of presenting the possible visual impacts, both positive and negative, arising from a proposed development.

There are many advantages of using this integrated approach, including unrestricted viewpoints, the simulation can switch between before, during and after development scenarios, many types

¹¹⁷ Screenshot and 3D model by the author (July 2002).

of visual impact information are available at a press of a key and complex data can be displayed graphically and can be combined with the VR world to make it more readily understood.

The disadvantages of using an integrated VR approach for VIA is that since the simulation uses real-time rendering the complexity of the VR model is restricted by the processing power of the computer on which it is run. For large environments, the detail of the VR model may have to be reduced which could lead to accuracy issues. Another disadvantage of this approach is that the user will need a certain degree of competence with using a computer in order to interact and navigate around the modelled environments.

Another possible disadvantage (which applies to Safe-VR and many other VR packages) is that the simulation might only run within the VR application it was developed in. This could give rise to distribution problems since a VR application may need to be purchased in order to run the simulation. However, some software packages allow the user to develop a VR simulation and then export it as a single or set of stand-alone files which do not require the development application to be present in order for the simulation to run (for example, Macromedia Director 8.5 Shockwave Studio).

5.6.3 An Integrated Approach Using Director

5.6.3.1 Methodology

Macromedia Director 8.5 Shockwave Studio was used to produce a VR simulation tool, entitled “Real-Time PVA Simulation”, which allows a user to navigate around a VR environment and determine the percentage view of various features of the environment in real-time and to access various other visual impact data. Figure 5.42 shows a screenshot from a Dene Quarry VR simulation produced using Director.

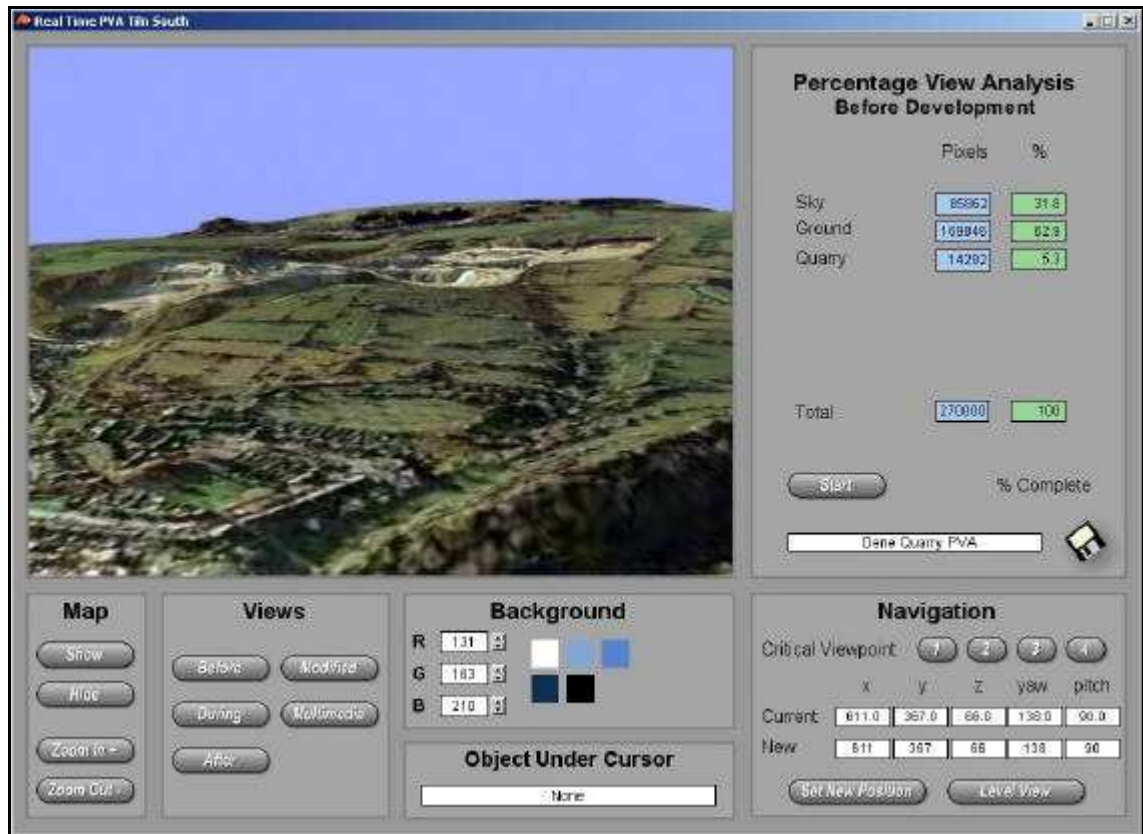


Figure 5.42: Real-Time PVA Simulation interface¹¹⁸.

The 3D CG environments used in the VR simulation were modelled using 3D Studio MAX 3.1 and exported as “W3D” files and then imported into Director. By importing before, during and after development models of an environment, the user is able to switch between each model, by clicking the corresponding button, to visualise how the development will look at the various development stages.

The user can also view multimedia such as photographs (figure 5.43), photomontages, maps, plans, animations and FVIs in regard to the development by clicking on the “multimedia” button.

¹¹⁸ 3D model and VR simulation created by the author (December 2002).

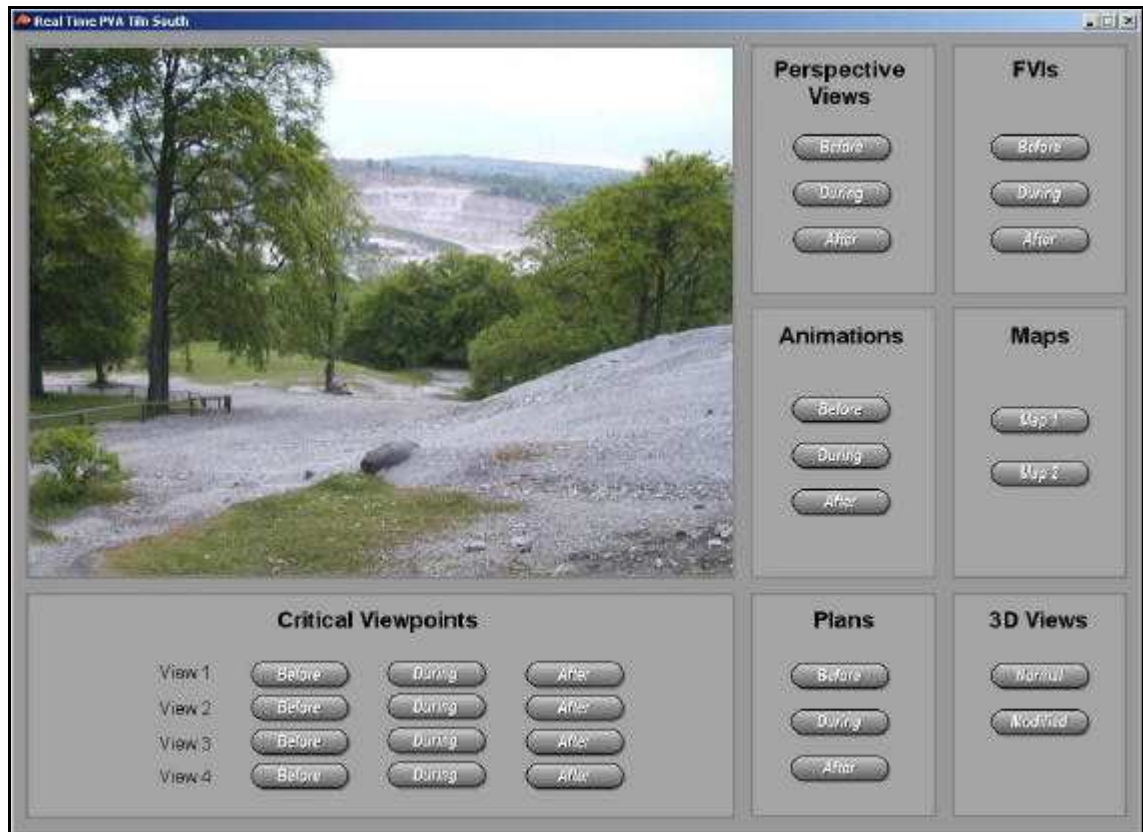


Figure 5.43: Photograph of Dene Quarry shown within Real-Time PVA Simulation¹¹⁹.

In order for a user to determine where they are currently located within the VR environment an overhead map can be toggled on and off and has the ability to be zoomed in or out. The map is updated in real-time as the user moves around the environment. The user can also navigate directly to pre-determined critical viewpoints by clicking on the appropriate critical viewpoint button. The user will also be rotated to look towards the proposed development. Alternatively, positional co-ordinates and yaw and pitch angles may be entered into the simulation for instant navigation.

Using the percentage view change technique, which has been described earlier in this chapter, it is possible to calculate the percentage view of various features of the environment in real-time. This is achieved by importing a copy of each 3D environment model, which have been modified so that the colours of the various features stand out from each other. For example, figure 5.44

¹¹⁹ Screenshot and VR simulation by the author (December 2002).

shows the altered model which corresponds to figure 5.42.

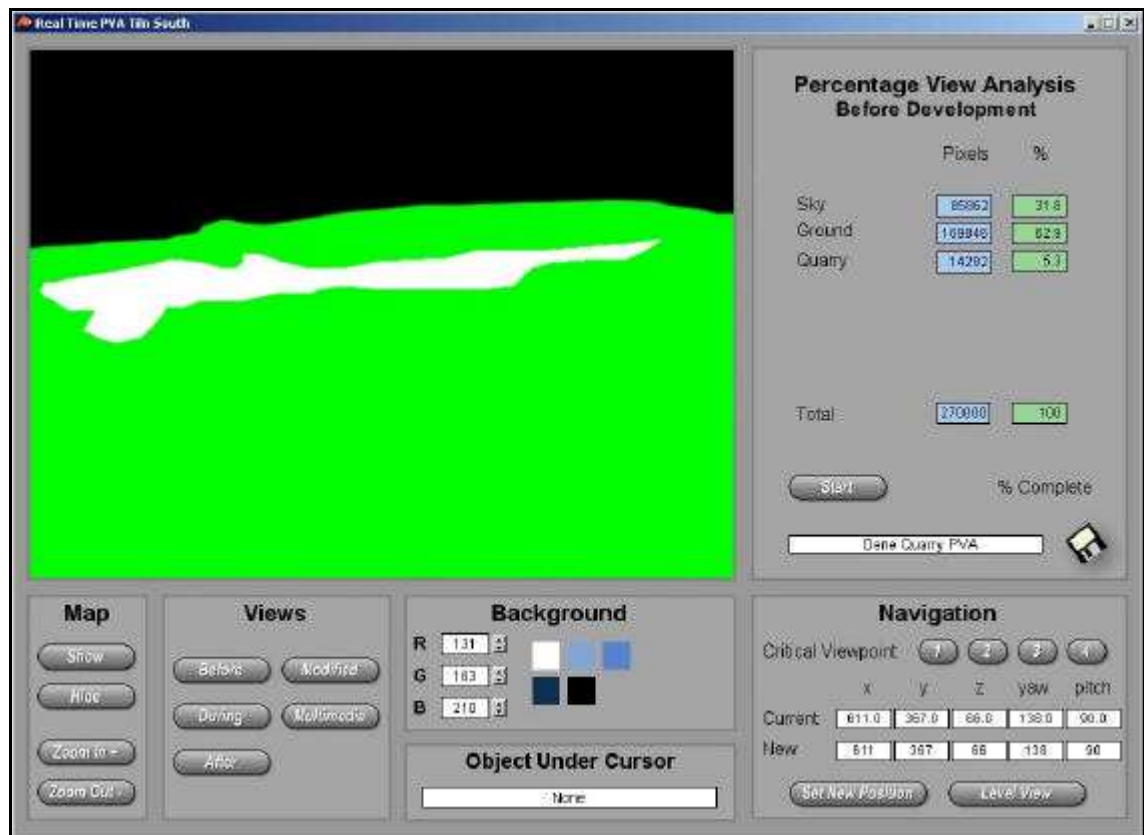


Figure 5.44: Alternate model used for determining the percentage view¹²⁰.

The ground has been coloured green, the quarry white, and the sky black. The simulation then analyses each pixel of the current altered model image and sorts them into one of the eight colour groups (shown earlier in table 5.2) and outputs the results to the screen. The results can then be saved to disk for subsequent analysis.

5.6.3.2 Analysis

Using Macromedia Director, a VR simulation technique has been developed which integrates various forms of VIA techniques, including real-time percentage view analysis, photomontages, animations and FVIs. This novel VR simulation technique was shown at the Ninth International

¹²⁰ 3D model and VR simulation created by the author (December 2002).

Conference on The Modelling, Monitoring and Management of Environmental Problems in Bergen, Norway (Cox and Schofield, 2002). There was a very positive feedback from both experts and peers, who appreciated the benefits of the interactive system over the traditional visualisation techniques.

This second approach for an integrated VR simulation contains all the features of the earlier Safe-VR approach, but is able to improve upon it by being able to perform percentage view calculations in real-time, which has the advantages of being quick to carry out and there are no restrictions on the viewpoint locations from which they can be performed. Another distinct advantage is that the simulation can be freely distributed, either on CD-ROM or over the internet, since the Macromedia Director software is not required for it to function.

As with the VR simulations created using Safe-VR, the complexity of the VR model is restricted by the processing power of the computer on which it is run and the user will need a certain degree of competence with using a computer in order to interact and navigate around the modelled environments.

5.7 Summary

A number of quantitative and spatial techniques to assess visual impacts have been developed or improved upon. At the heart of the techniques are 3D CG models produced using 3D modelling and animation software. Many of the techniques that have been developed use MAXScript utilities whilst other techniques rely upon 3D modelling techniques.

It has been shown that accurate FVIs can be quickly produced without the need for specialist FVI software by using the shadows cast by lights placed at a viewpoint location. It has also been shown that visual changes due to a proposed development can be quantitatively assessed either in real-time using a VR simulation or, more accurately, within the 3D CG modelling

environment using the Bitmap Colour Counter utility.

For all of the techniques described above, detailed surface features such as hedges, semi-transparent vegetative screening, or walls can be taken into account when assessing the change in view due to a proposed development. Other factors such as Earth curvature and atmospheric refraction, seasonal variation and vegetative growth can also be taken into account using simple 3D CG modelling and animation techniques.

The various visual impact results can all be combined in an integrated VR simulation where the user has unrestricted access to the proposed development and its surrounding environment. This type of approach has the advantage that many different types of visual impact information are available within the simulation, the environment can be easily visualised pre, during and post development and complex data can be displayed graphically so that it is more readily understood by all.

Chapter 6 presents a number of real world case studies which use and apply these new techniques to assess the visual impacts that may arise due to the various proposed developments. The chapter also gives a critical appraisal of the results gained from these techniques.

6 Case Studies

6.1 Introduction

The new and enhanced VIA techniques which were described in chapter 5 have been applied to a number of case studies, some of which have been briefly presented in earlier chapters. Three major case studies are presented below that demonstrate how these new and enhanced techniques can be integrated and applied to assess the visual impact of proposed developments. It is proposed that the application of these techniques solves some of the problems associated with computerised VIA techniques that were illustrated in chapter 4.

6.2 Stoke Approach Corridor Study

6.2.1 Introduction

Babtie Group urban and landscape designers were appointed by Stoke City Council and the Stoke Approach Partnership to provide proposals for the creation of a new image and appearance for the corridor surrounding the three principal transportation routes into Stoke on Trent, North Staffordshire.

As the study progressed, themes and general recommendations were amalgamated into three major, catalytic project areas; the Hartshill area, the Station area and the Old Football Ground area. The author was asked to produce two panoramic animations (one showing the environment pre-development and one showing the environment post-development) of the Hartshill area from a single key viewpoint, which was from a proposed viewing platform located in Hartshill Park. The main aim of these rendered animations was to provide before and after visualisations of the area to aid the decision making process. Figure 6.1 shows the Hartshill area with the proposed viewing platform location and direction of view highlighted. The view from this viewpoint is shown in figure 6.2 which is a panoramic photograph provided by Babtie Group (the bottom section represents the right portion of the photograph).



Figure 6.1: The Hartshill area¹²¹.



Figure 6.2: Photographs from the key viewing location¹²².

¹²¹ Photograph from Bابتie Group (2000a).

¹²² Photograph from Bابتie Group (2000a).

The main aims of the Hartshill scheme were to create a landmark in the form of a landscape beacon (figure 5.3), a bridge beacon, a pedestrian and cycle link and new planting to strengthen and extend existing vegetation.

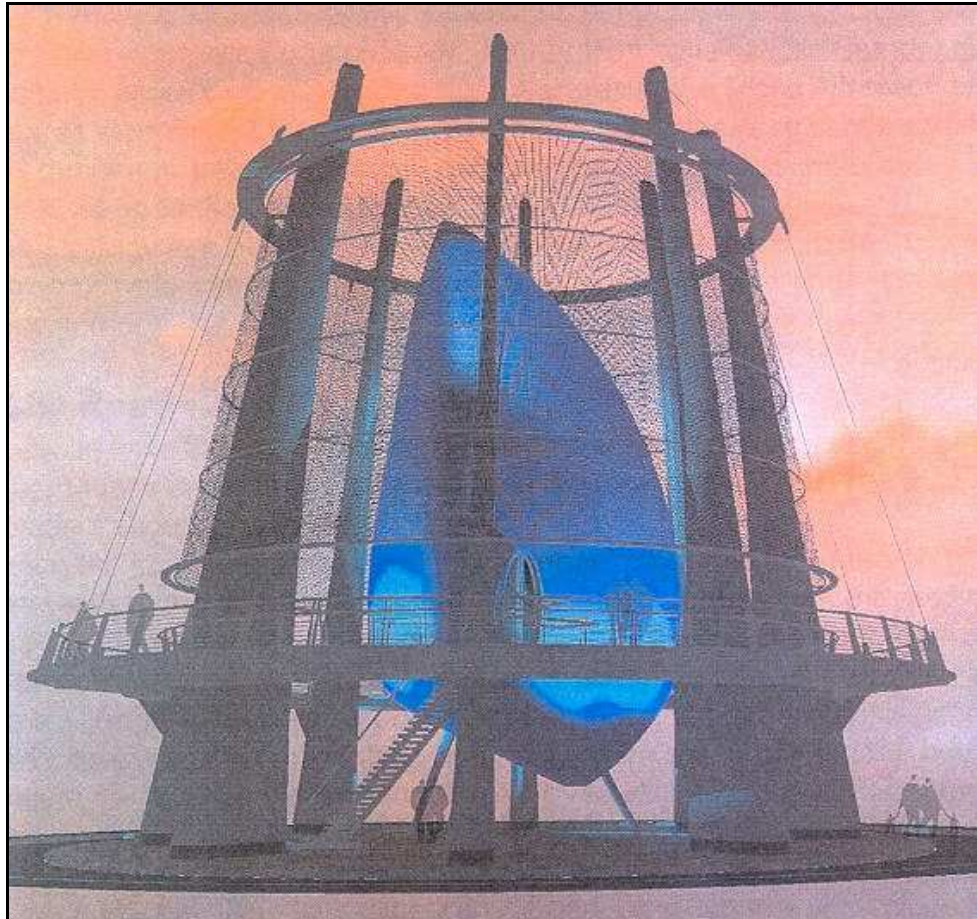


Figure 6.3: Rendered image of proposed landscape beacon¹²³.

6.2.2 Data Acquisition

Babtie Group provided a limited amount of data consisting of CAD data, a project plan and aerial perspective photos of the area. The CAD data provided ground plan and contour information of the Hartshill area and also the proposed model of the landscape beacon. However, the information from Babtie Group was not detailed enough to provide accurate 3D measurements of many of the existing structures within the area to be modelled and the

¹²³ Image from Babtie Group (2000b).

photographs were unable to provide images detailed enough to be used for texture mapping. Therefore, dimensions of existing structures had to be estimated using the photographs provided and textures had to be created as required.

6.2.3 Modelling

The contour CAD data was imported into 3D Studio MAX in the form of a number of splines (figure 6.4). The splines were then converted into a DEM using the “terrain” function, which is a process in which the vertices from the splines are triangulated with neighbouring vertices to form a number of faces. The terrain object was then textured with a bitmap image of the ground, which was created with Paint Shop Pro using the aerial photographs as a guide.

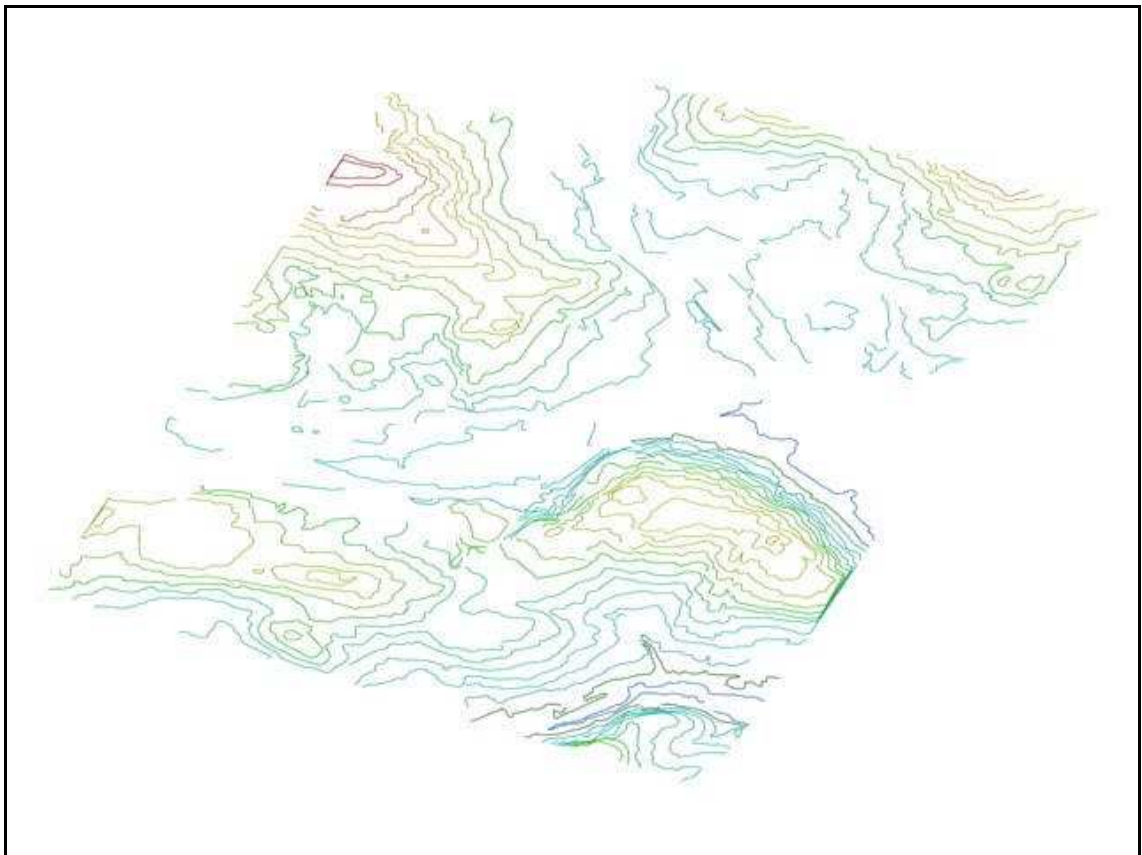


Figure 6.4: Contour splines for the Hartshill area¹²⁴.

¹²⁴ Image from a 3D model created by the author (February 2000) from data supplied by Babbie Group Group (2000a).

The ground plan CAD data was also imported into 3D Studio MAX in the form of a number of splines (which represented the centre lines for roads, railway lines and footpaths) and used as a guide for building locations. Buildings and other structures were created using a combination of primitive objects (such as boxes, cylinders and spheres) and extruded lines. The shape and form of the buildings and structures were extrapolated from the photographs and positioned using both the photographs and CAD ground plan data as a guide. Textures were then applied to the buildings and structures using bitmap images which were created using the photographs as a visual aid.

Exact tree locations were unknown, so the photographs were once again used to position their locations. The 3D Studio MAX Forest plug-in was used to model groups of trees using a spline to delineate their perimeter and the Planes plug-in was used to model individual trees (both plug-ins are described in appendix 1). In each case, single sided planes were used to represent each tree and appropriate tree textures, consisting of a tree bitmap image and its respective opacity bitmap, applied to each. The tree models were then placed on the surface of the terrain model and attached to a virtual camera, placed at the proposed viewing platform location. Therefore if the camera moves, all the trees would rotate on their vertical axis to face the camera and hence the viewer would not notice that the trees were simple 2D objects.

A background for the model was created using the panoramic photographs (as shown in figure 6.2) mapped onto a cylinder which surrounded the environment. A fog effect was then applied in such a way as to blend the far extremity of the model into the background. A foreground was also added to the model in order to portray the vegetation located in the vicinity of the viewing platform. A bitmap texture was created using the foreground vegetation in the panoramic images (figure 6.5) and a corresponding opacity map created so that only the foreground vegetation could be seen (figure 6.6). These two textures were then applied to a plane object which was placed in front of the camera.



Figure 6.5: Foreground image¹²⁵.



Figure 6.6: Foreground mask¹²⁶.

An omni light was added to the model and positioned in such a way as to simulate the lighting conditions from the panoramic photographs (shown in figure 6.2). Figure 6.7 shows an image of the finished pre-development model, which represents existing conditions, rendered from the camera positioned at the proposed viewing platform. The foreground image can clearly be seen in the foreground, with the 3D models in the middle of the scene blending seamlessly into the background image at the rear.



Figure 6.7: Rendered image of the Hartshill area before development¹²⁷.

¹²⁵ Image by the author (February 2000).

¹²⁶ Image by the author (February 2000).

¹²⁷ Image from a 3D model created by the author (February 2000).

The pre-development model was copied and edited to produce an post-development model which represented the landscape after the proposed developments had been put in place. Changes to the model included the addition of the landscape beacon, the beacon bridge, the pedestrian and cycle link and new vegetation. To make way for the landscape beacon, the timber yard structure had to be removed from the model and the ground surface texture map altered slightly to give the appearance of landscaped gardens around the beacon.

The landscape beacon was created by importing the CAD data for the landscape beacon into 3D Studio MAX and texturing the object with simple blue and grey colours using Babtie Group's project plan as a guide. The beacon was then placed into position based on Babtie Group's project plan. Figure 6.8a shows the landscape beacon wireframe mesh model after it was imported into 3D Studio MAX and 6.8b shows the model after texturing.

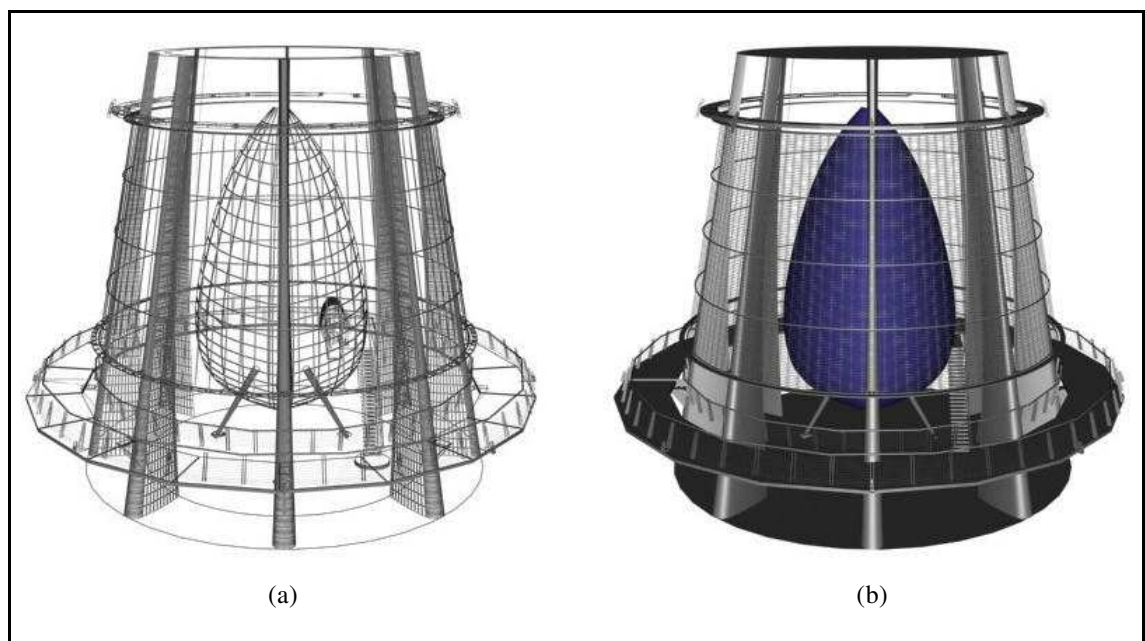


Figure 6.8: Landscape beacon models ¹²⁸.

There was no data supplied for the modelling of the beacon bridge other than a photomontage which Babtie Group had prepared in their project plan (figure 6.9). Using this photomontage as a guide, the beacon bridge was modelled by modifying a cylinder primitive to form the shape

¹²⁸ Images by the author from a 3D CAD model by Babtie Group (2000a).

shown in the image. The first step was to taper the cylinder (figure 6.10a) so that it was thinner in the middle than at the ends (figure 6.10b). The tapered cylinder was then bent to form an arch (figure 6.10c). The vertices of the arch were then raised to form the final bridge beacon shape (figure 6.10d). The model was then given a grey colour and placed into position.

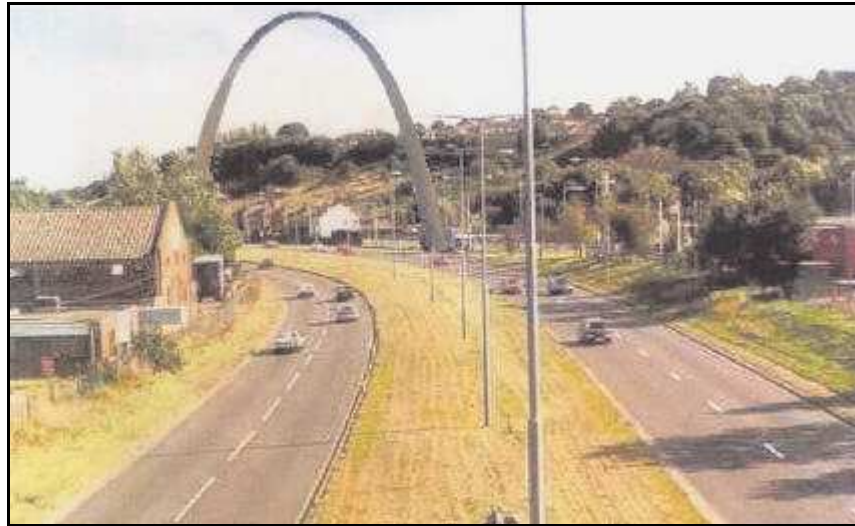


Figure 6.9: The beacon bridge photomontage¹²⁹.

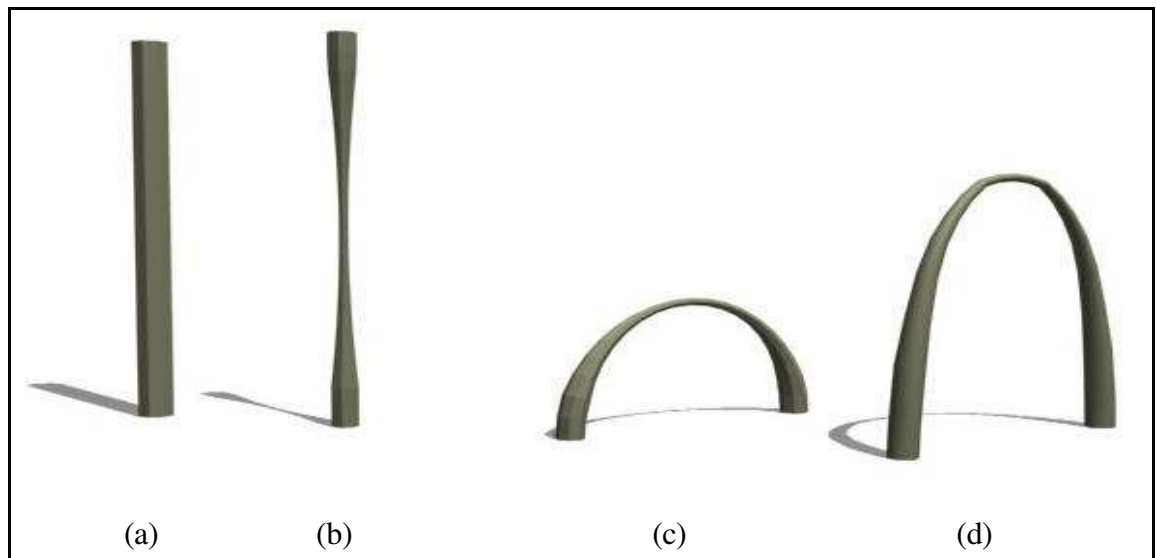


Figure 6.10: Stages in modelling the Beacon bridge¹³⁰.

Like the beacon bridge, there was limited data on the pedestrian and cycle link apart from some sketches and photographs of similar existing designs. The link consisted of two bridges

¹²⁹ Photomontage from Babbie Group (2000b).

¹³⁰ Images from a 3D model created by the author (February 2000).

connected by an elevated walkway. Extruded splines were used to model the walkway and handrail sections and modified box primitives were used to model the walkway supports. Figure 6.11 shows a section of the pedestrian and cycle link. Figure 6.12 shows an image of the finished post-development model, which represents the view from the proposed viewing platform located in Hartshill Park, with the proposed developments in place.

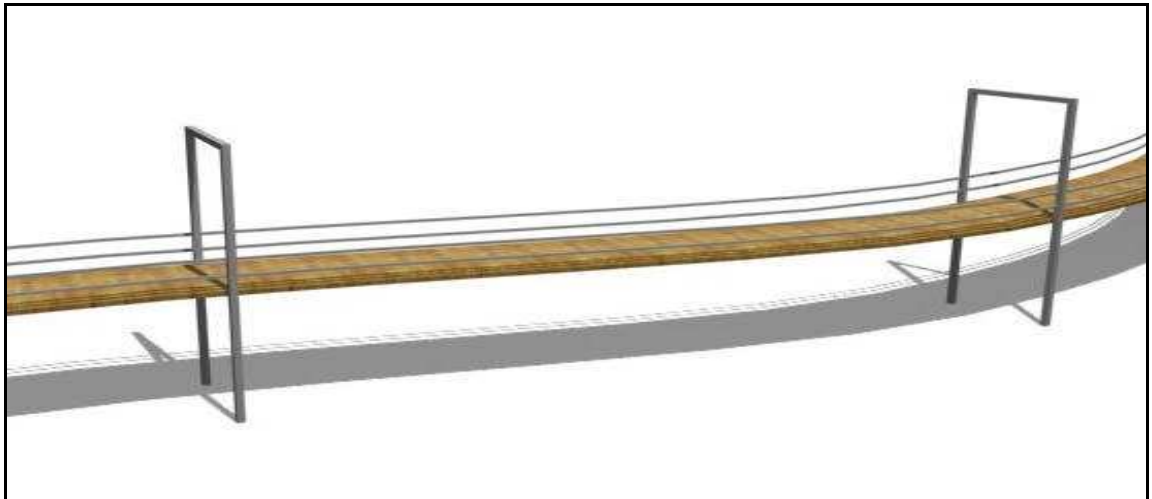


Figure 6.11: Part of the elevated walkway of the pedestrian and cycle link¹³¹.



Figure 6.12: Rendered image of Hartshill area from selected viewpoint post-development¹³².

¹³¹ Image from a 3D model created by the author (February 2000).

¹³² Image from a 3D model created by the author (February 2000).

6.2.4 Animations

Two animations were required by Babbie Group; one animation showing the existing landscape and the other showing the landscape with Babbie Group's proposed developments in place. The animations were produced by simply rotating the proposed viewing platform cameras in both models back and forth over five hundred frames on their vertical axis so that all of the proposed changes were visible.

A third extra animation was also produced to show the before and after views merging into one another in order to help visualise the proposed changes to the Hartshill area in context. This third animation was created using Adobe Premiere 5.1 (Adobe Systems Inc., 2003) by transitioning between static rendered images of the before and after models. These animations can be found on the CD-ROM in appendix 9.

6.2.5 Percentage View Change Analysis

A percentage view change analysis using the Bitmap Colour Counter was not possible at the time of this project since the software had not yet been developed. However, the Stoke project was used as a case study to test the Bitmap Colour Counter utility soon after its development by assessing the percentage view of the proposed developments and the percentage change in view of existing features within the environment.

Using the technique described earlier in chapter 5, the pre-development and post-development models were "colour modified" so that each of the features within the models was given a unique colour (as outlined in chapter 5, table 5.2) whilst leaving any opacity maps that were present intact. Table 6.1 shows which colours were applied to which models.

Colour	Before development model	Post-development model
Black	Foreground and background	Foreground and background
White	Surface	Surface
Green	Vegetation	Vegetation
Cyan	Buildings and structures	Buildings and structures
Blue	Not applicable	Landscape beacon
Yellow	Not applicable	Beacon bridge
Magenta	Not applicable	Pedestrian and cycle link

Table 6.1: Application of colour to features within the before and after models.

Images were then rendered from the selected viewing location for the modified pre-development and post-development models with a aspect ratio of 4:3 at a resolution of 800 by 600 (figures 6.13 and 6.14 respectively). The two images were then analysed by the Bitmap Colour Counter software utility and the results saved as delimited text files.

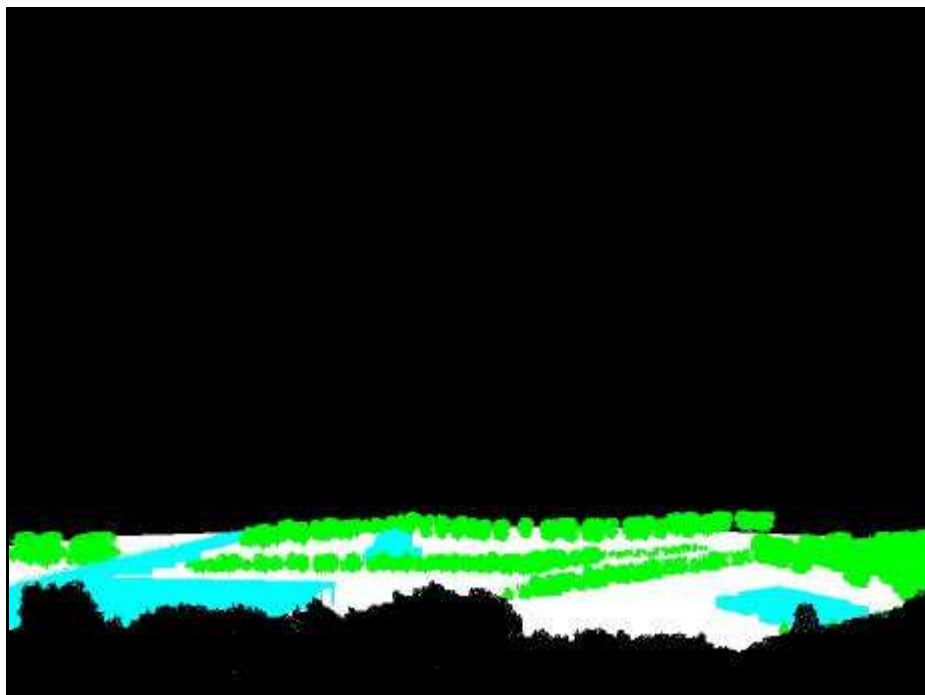


Figure 6.13: Rendered image from the colour modified pre-development model¹³³.

¹³³ Image from a 3D model created by the author (January 2001).

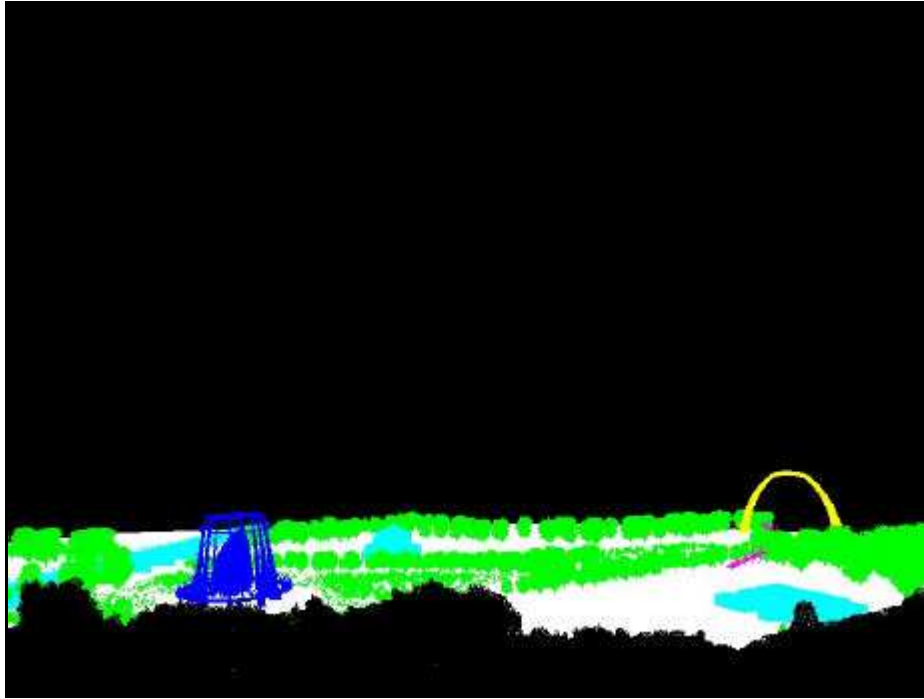


Figure 6.14: Rendered image from the colour modified post-development model¹³⁴.

Using a spreadsheet software package (in this case Microsoft Excel), the text files were formatted to produce table 6.2 which shows the percentage view of each model feature for both the pre-development and post-development models. The table also shows the percentage view change of the existing landscape due to the changes proposed by Babbie Group.

	Landscape Beacon	Beacon Bridge	Pedestrian and Cycle Link	Vegetation	Buildings and Structures	Surface	Foreground and Background
Pre-development	0.00	0.00	0.00	5.07	2.55	5.39	86.99
Post-development	0.93	0.16	0.05	5.96	1.07	4.97	86.86
Change	0.93	0.16	0.05	0.89	-1.48	-0.42	-0.12

Table 6.2: Percentage view of various features within the 3D model from the viewing platform.

The results show that there will be an increase in view of vegetation by 0.89 percent and a decrease in view of existing buildings and structures, ground surface, and foreground and

¹³⁴ Image from a 3D model created by the author (January 2001).

background by 1.48, 0.42 and 0.12 percent respectively. The proposed landscape beacon, beacon bridge, and pedestrian and cycle link will impart percentage views of 1.44, 0.24 and 0.07 respectively.

6.2.6 Analysis

The Stoke Approach Corridor Study involved minimal modelling due to the fact that foreground overlays and background images were used within the model. Therefore, within a short time span of one week, two models representing the existing landscape and the proposed landscape of the Hartshill area were modelled and animations produced. The animations helped Babbie Group to convey their ideas for the development of the Hartshill area to Stoke City Council Officers and various other people and groups involved in the decision making process. Both Babbie Group and the Stoke City Council Officers were positive about the visualisations and this provided useful feedback for the development process.

A combination of qualitative and quantitative techniques have been used to assess the visual change that may occur to the Hartshill area due to proposed developments by Babbie Group. Animations showed the visual change qualitatively while the percentage view change figures obtained from the pre-development and post-development models gave a quantitative indication of the extent of visual impact bestowed on the Hartshill area. The techniques used in this case study do not aim to assess the change in the aesthetic value of the landscape since this is a purely subjective discipline which varies according to personal preference.

6.3 Birmingham University Hospital Case Study

6.3.1 Introduction

Babbie Group requested a number of static visualisations and a percentage view change analysis to be included in an EIS for a new university hospital in Birmingham. The project is outlined by

Gross (2001):

“Babtie Group are providing multi-disciplinary expertise for the development of the first major new hospital in Birmingham for over sixty years. They have worked alongside urban planning and transportation consultants to provide reassurance that the hospital, to be constructed by PFI consortium, would be built to the satisfaction of the City Council, adhering to principles of sustainability, good landscape design and nature conservation.”

The planned location for the new university hospital was currently occupied by a psychiatric hospital and it was therefore proposed to move the existing psychiatric hospital to a new site situated a few hundred metres south (figure 6.15). However, the proposed location for the psychiatric hospital was a Site of Special Scientific Interest (SSSI) and therefore an EIA was of particular importance for the project, which would include a detailed VIA of the proposed developments. Babtie Group has split this project into two sub-projects, each with their own EIS: the development of the new university hospital, and the re-allocation of the psychiatric hospital.

Babtie Group requested visualisations from numerous locations, some of which were situated over a kilometre away from the proposed university hospital site. Hence the case study involved the modelling of approximately two square kilometres of land, which included the existing hospital site, Birmingham University, and numerous residential areas.

The 3D CG model was used to produce visualisations and a percentage view change analysis of the new university hospital from critical viewpoints identified by Babtie Group and also from a local residential tower block. A VR simulation of the new university hospital was also produced using Safe-VR. For the psychiatric hospital, visualisations were also produced and a percentage view change analysis for each critical viewpoint and the local residential tower block was performed.

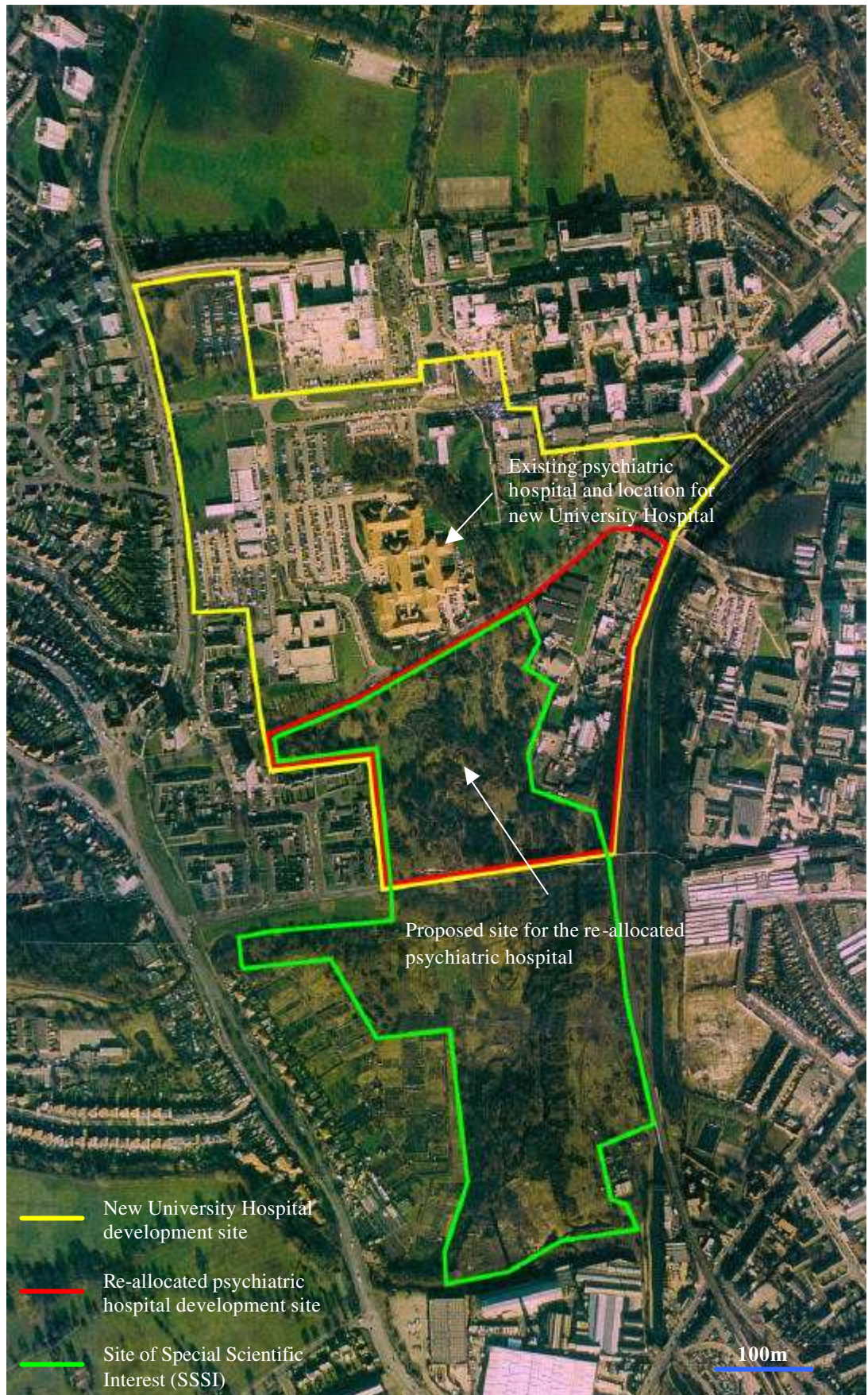


Figure 6.15: Aerial view of proposed site¹³⁵.

¹³⁵ Image modified by the author (March 2003) from an aerial image from Babtie Group (2000c).

6.3.2 Data Acquisition

Babtie Group provided a large amount of data for this project ranging from an aerial photograph (shown in figure 6.15), printed and digital CAD data and vegetation surveys. The CAD data varied in detail and included:

- ?? road layouts,
- ?? building locations,
- ?? vegetation locations (figure 6.16),
- ?? contour data,
- ?? un-textured 3D model of the proposed university hospital,
- ?? un-textured 3D model of the psychiatric hospital (figure 6.17),
- ?? basic 3D models of some of the neighbouring buildings.

Although a basic CAD model of the new university hospital was initially provided, the hospital design changed during the modelling process and therefore plan view CAD data and hand drawn sketches were later provided by Babtie Group.

The CAD data also provided basic 3D models of some of the neighbouring buildings, but the models were found to be inaccurate (the buildings were created using splines which only delineated the perimeter of each building and extruded to a standard height) and hence they were discarded.

The vegetation surveys provided detailed information on the types of vegetation, their height and canopy width. This allowed the accurate placement of vegetation with appropriate vegetative textures. A day was also spent in Birmingham, collecting digital photographs, of buildings and vegetation surrounding the site, to use as textures for the 3D model.

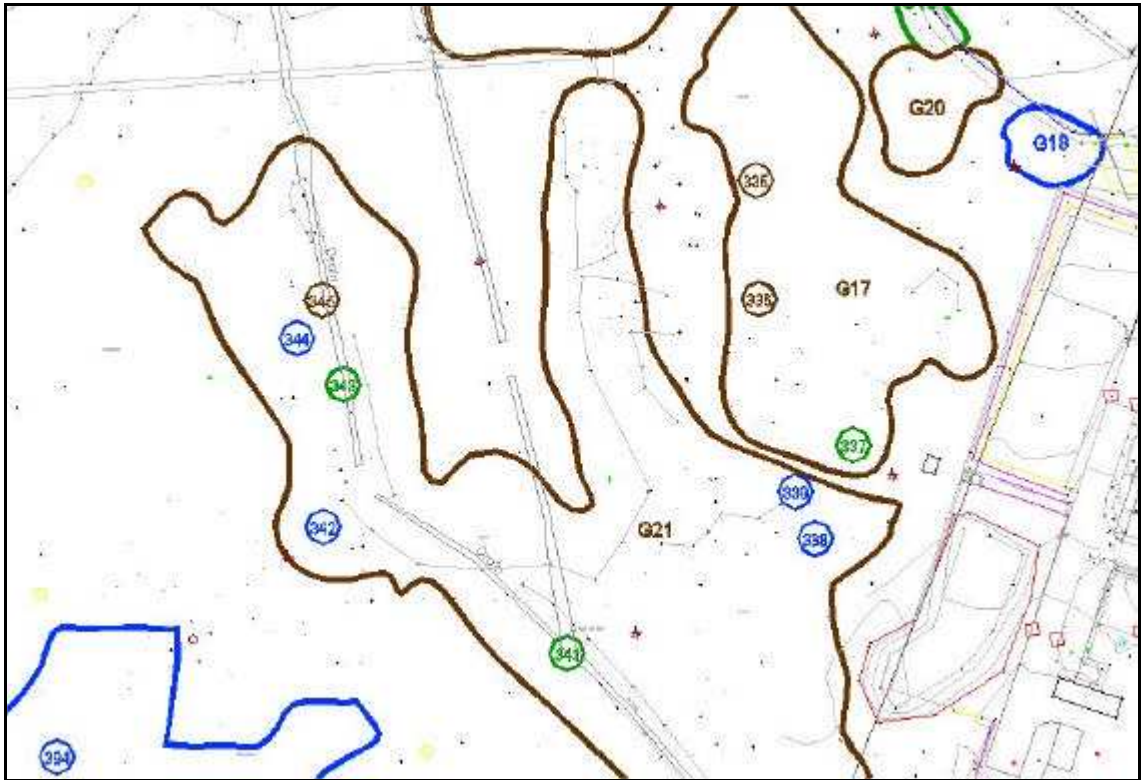


Figure 6.16: Example of digital CAD data showing the location of various vegetative species¹³⁶.

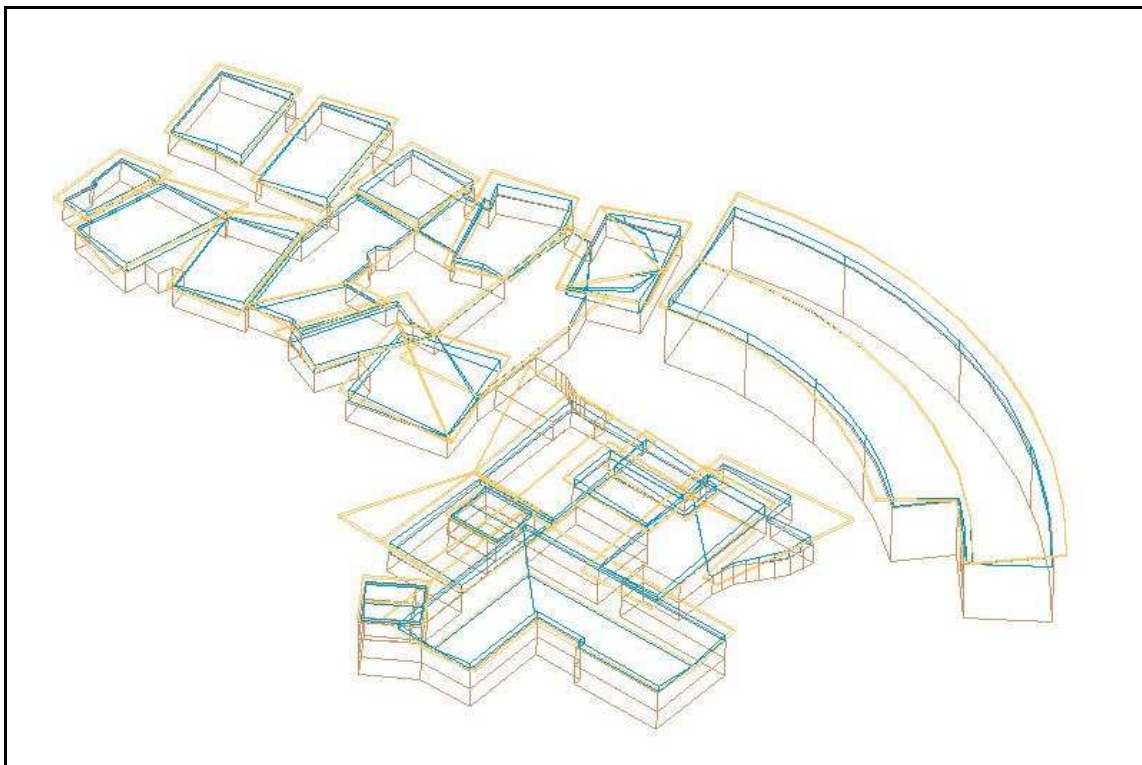


Figure 6.17: Digital CAD data showing one of the proposed psychiatric buildings¹³⁷.

¹³⁶ CAD data supplied by Babbie Group (2000c).

¹³⁷ CAD data supplied by Babbie Group (2000c).

6.3.3 Development Of The New University Hospital

6.3.3.1 Modelling

The digital CAD contour, road, vegetation and building layout data were imported into 3D Studio MAX version 3.1 as a set of splines. The contour data consisted of five metre contours surrounding the proposed site and more detailed two metre contours for the site itself. Using the terrain function, a DEM was created using the contour splines (figure 6.18). The aerial photograph, which was cropped and resized using Paint Shop Pro, was then used as a texture map for the surface DEM and positioned and scaled into place using the road and building layout splines. A second surface texture map, which represented the ground surface after the development of the university hospital, was also created by editing the existing ground surface texture map using Paint Shop Pro.

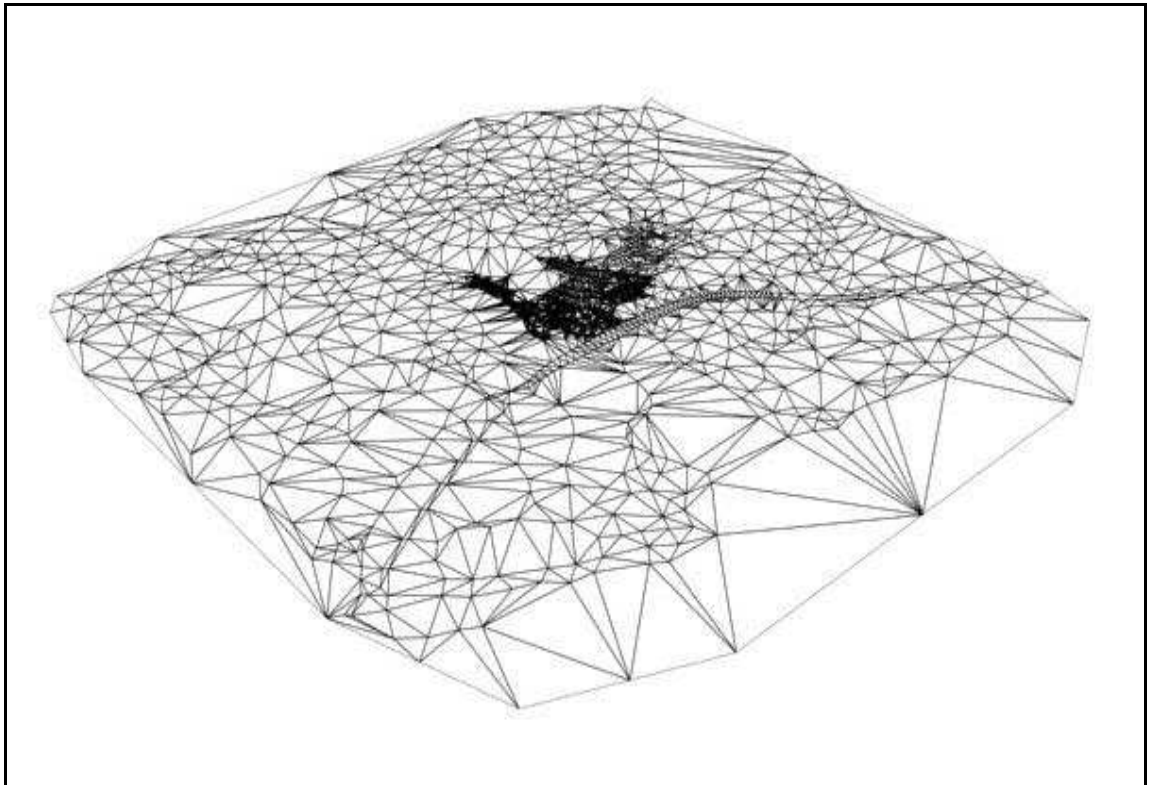


Figure 6.18: Surface terrain mesh. Detailed 2m contours can be seen in the centre of the mesh¹³⁸.

¹³⁸ Image from a 3D model created by the author (May 2000)

Buildings were constructed using a combination of modified primitives and extruded splines. The CAD building layout data was used as a positioning guide for the splines and also to position buildings, such as houses, which were not created using extruded splines. Information on the height of the buildings was not provided, so the digital photographs were used to establish their heights. The buildings were textured using images created from the digital photographs.

The new university hospital was created using a number of modified primitives from sketch drawings and a CAD plan view of the proposed design and textured using grey coloured materials as suggested by Babbie Group (figure 6.19). The 3D model of the new hospital was fairly crude since the final architectural details had not yet been finished at that stage.

The vegetation CAD data which was imported into 3D Studio MAX was used to create a number of splines which were then used for creating groups of trees using the Forest plug-in software (described in more detail in appendix 1). Planes were used to create individual trees and positioned according to the CAD vegetation data. All the vegetation models were positioned on the surface of the terrain model and linked to a virtual camera.

The tree survey was used to correctly size and texture the vegetation. Some of the vegetation textures were created from the digital photographs which were taken on the site visit, which helped to improve the accuracy and realism of the model. For other vegetation, textures that represented the appropriate species of vegetation were chosen from an image library.

The vegetation models were then arranged into groups according to whether they were visible during both pre-development and post-development, only pre-development, or only post-development. A background was also added to the model using a hemisphere that enclosed the terrain model and textured with a cityscape image to provide a skyline.

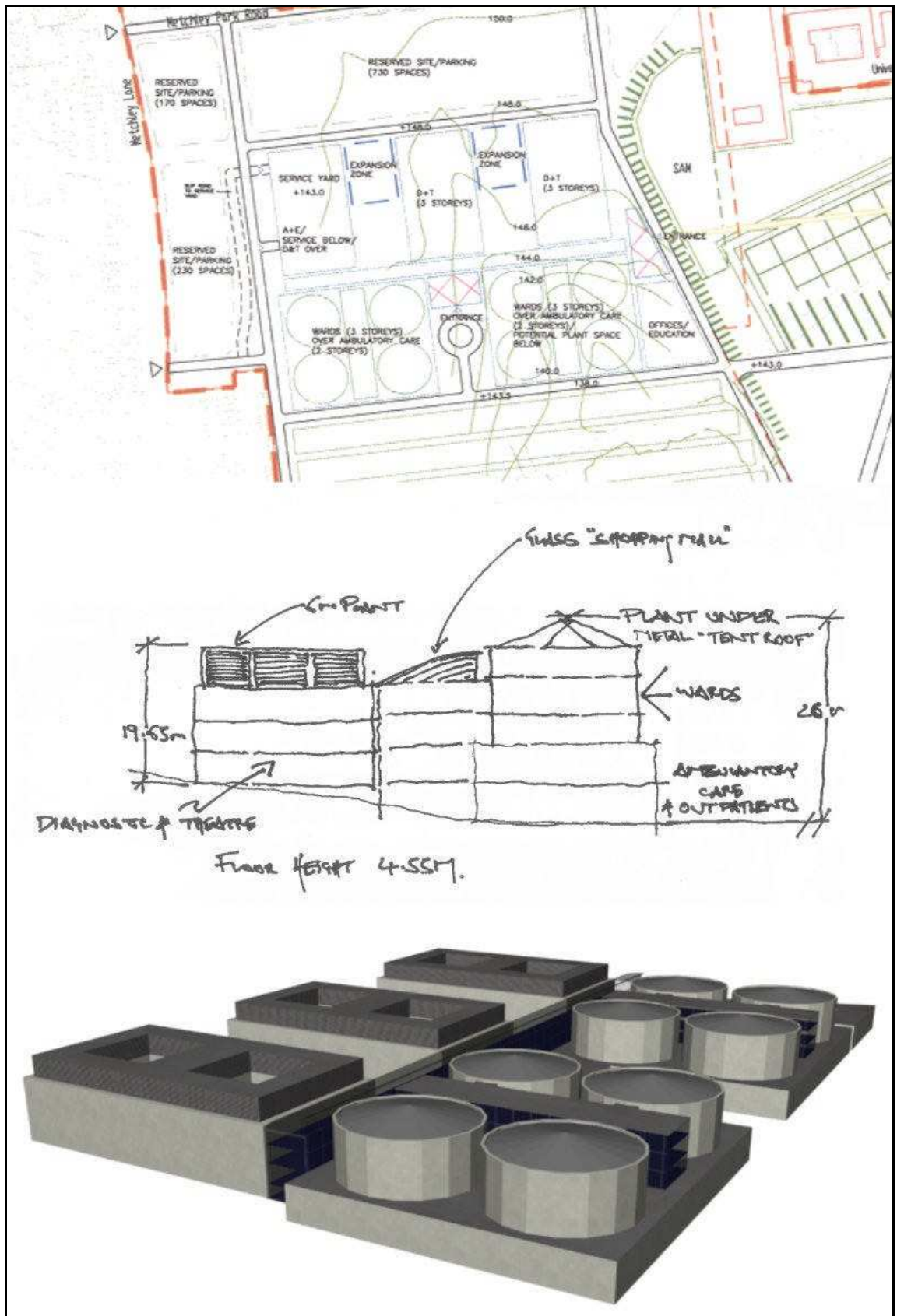


Figure 6.19: CAD plan, sketch drawing and rendered image of the new university hospital¹³⁹.

¹³⁹ CAD and sketch image from Babtie Group (2000c) and rendered image from a 3D model by the author (May 2000).

Photographs were taken by Babtie Group from seven critical viewpoints, that they had chosen, looking towards the proposed university hospital site (figure 6.20). These critical viewpoints were replicated within the 3D CG model by placing a virtual camera at each location. Lighting was also added to the model using an omni light positioned so as to cast shadows similar to those seen on the aerial photograph.



Figure 6.20: Location and direction of critical viewpoints¹⁴⁰.

¹⁴⁰ Image modified by the author (March 2003) from an aerial image from Babtie Group (2000c).



Figure 6.21: Rendered image of the proposed university hospital site before development¹⁴¹.



Figure 6.22: Rendered image of the proposed university hospital site post-development¹⁴².

¹⁴¹ Rendered image from a 3D model created by the author (May 2000).

¹⁴² Rendered image from a 3D model created by the author (May 2000).

By hiding certain features within the 3D model it is possible to switch between a pre-development scenario and a post-development scenario. Figures 6.21 and 6.22 show rendered images of the pre-development and post-development models respectively.

6.3.3.2 Visualisations

Rendered images were produced for each of the critical viewpoints with the proposed university hospital in place. For critical viewpoints one to six, the rendered images were combined with the critical viewpoint photographs using Paint Shop Pro to produce photomontages (the process of creating an accurate photomontage has been explained in chapter 3). Critical viewpoint seven, a view from a high rise tower block, was not developed into a photomontage since the corresponding photograph was unsuitable.

Figure 6.23 shows the photomontage from critical viewpoint two after the development of the university hospital. Appendix 7 shows the photomontages from critical viewpoints one to six and the rendered image from critical viewpoint seven.



Figure 6.23: Photomontage from critical viewpoint two showing the proposed university hospital¹⁴³.

¹⁴³ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie Group (2000c).

Animations of the proposed university hospital site were also created for the pre-development model and the post-development model. A virtual camera was set up to orbit around the outskirts of the site while looking down towards the centre of the site and animated over nine hundred frames at thirty frames per second to produce thirty second animations for the pre-development and post-development model. These animations can be found on the CD-ROM in appendix 9.

6.3.3.3 Percentage View Change Analysis

For each critical viewpoint, the percentage view of the new university hospital and the percentage view change in vegetation due to the new hospital were determined. The pre-development and post-development 3D CG models were colour modified so that vegetation was green and the new university hospital buildings red. All other features within the model were coloured black.

The view from each critical viewpoint was then rendered for both models with an aspect ratio of 4:3 and at a resolution of 800 by 600. For accurate percentage view change analysis, the colour modified rendered images for critical viewpoints one to six were combined with their respective photographs to produce photomontages. However, the photograph portions of the images were coloured white. Figure 6.24 shows the colour modified rendered photomontage from critical viewpoint two after the development of the university hospital.

The images were passed through the Bitmap Colour Counter utility for analysis. Formatted results from the seven critical viewpoints are shown in table 6.3. Critical viewpoints three and five resulted in the largest increase in view of both vegetation and the proposed university hospital at the expense of ground coverage and skyline. Critical viewpoint four also had an increase in view of vegetation and the proposed university hospital, but to a lesser extent.

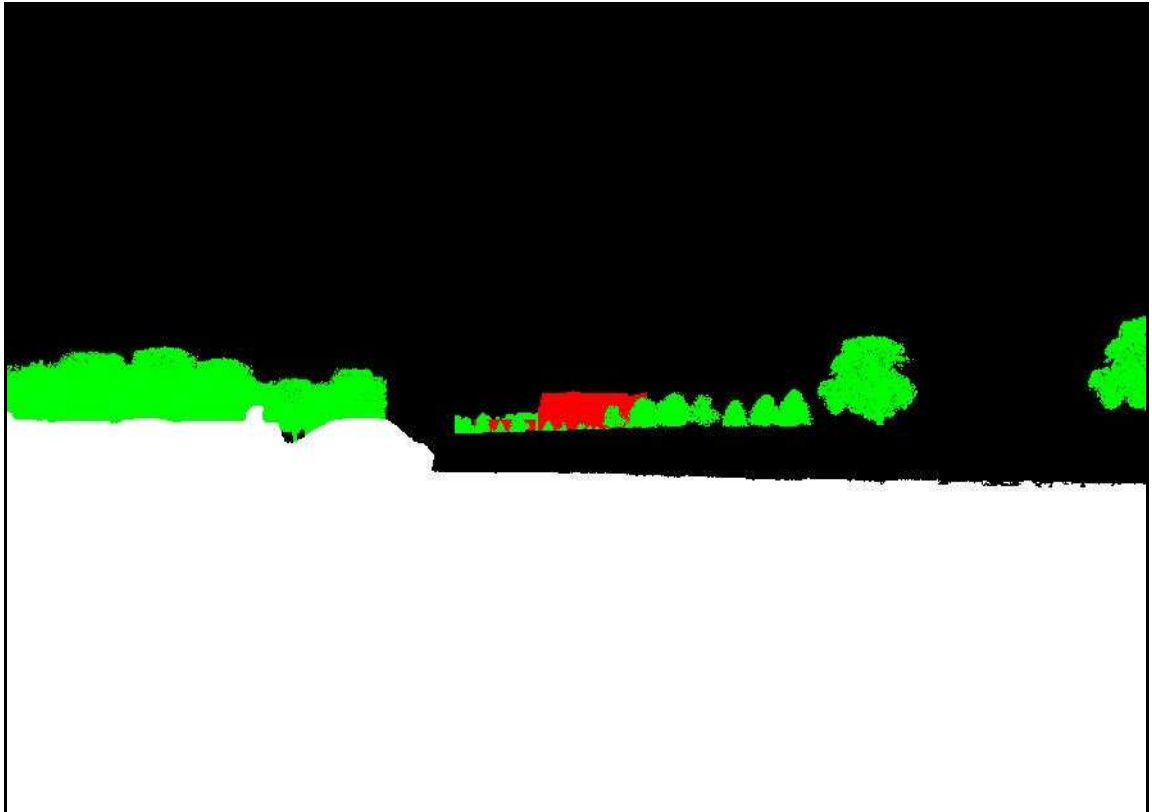


Figure 6.24: Colour modified image from critical viewpoint two after the hospital development¹⁴⁴.

Critical Viewpoint	Percentage View of Vegetation			Percentage View of University Hospital
	Pre-development	Post-development	Change	
1	0.00	0.01	0.01	0.60
2	4.24	3.95	-0.30	0.35
3	1.93	15.95	14.02	9.99
4	3.46	3.63	0.17	2.59
5	0.73	7.20	6.47	4.31
6	6.22	5.87	-0.35	0.68
7	16.45	15.78	-0.67	0.90

Table 6.3: Percentage view of vegetation and proposed university hospital from critical viewpoints.

These results are not unexpected since critical viewpoints three, four and five are located very close to the proposed site. It was also found that critical viewpoint one would hardly be affected

¹⁴⁴ Image from a 3D model created by the author (May 2000) and a photograph by Babbie Group (2000c).

by the development of the new university hospital and this is because the Women's Hospital shields the view. The largest loss in view of vegetation, although this was still minimal, resulted from critical viewpoint seven and this was due to the clearing of trees on the proposed university hospital site.

A percentage view analysis was also performed from a nearby residential tower block which has windows situated on the north side of the building that overlook the proposed site. The tower block consists of eleven floors, with two windows that face the site on each floor. For each of these twenty two windows, a rendered image was produced using the colour modified pre-development and post-development models and using Animation Shop (a software package that comes with Paint Shop Pro and which can create animations from a series of raster images), an uncompressed animation was produced using these images. The animation was then passed through the Bitmap Colour Counter, the results saved to file and table 6.4 produced.

Window	Percentage Decrease in Vegetation	Percentage View of University Hospital
1	7.86	7.53
2	6.49	7.35
3	8.08	7.14
4	6.33	6.97
5	7.97	6.75
6	6.38	6.60
7	8.37	6.36
8	6.82	6.22
9	8.57	5.93
10	6.36	5.79
11	7.56	5.36
12	5.49	5.21
13	6.55	3.83
14	4.91	3.83
15	6.25	2.63
16	4.68	2.71
17	7.03	1.70
18	5.45	1.76
19	7.59	0.69
20	6.20	0.86
21	8.09	0.23
22	6.71	0.31

Table 6.4: Results of the percentage view analysis for the tower block (windows are ordered starting at the top left window, working across and then down).



Figure 6.25: View of the tower block showing the percentage view decrease in vegetation¹⁴⁵.



Figure 6.26: View of the tower block showing the percentage view of the proposed hospital¹⁴⁶.

¹⁴⁵ 3D model created by the author (May 2000).

¹⁴⁶ 3D model created by the author (May 2000).

To graphically visualise the results, the windows of the tower block texture map were shaded according to the percentage change in view of vegetation and percentage view of university hospital, and perspective views of the tower block were then rendered with the new tower block texture maps applied (figures 6.25 and 6.26).

The results showed a fairly uniform decrease in percentage view of vegetation, ranging from 4.68 percent to 8.57 percent. However, as expected, the higher the window, the greater the percentage view taken up by the new hospital. The percentage views taken up by the new university hospital from the ground floor windows were 0.23 and 0.31, whilst the percentage views taken up by the new university hospital from the top floor windows were 7.35 and 7.53 percent.

6.3.3.4 Integrated Visual Impact Assessment Using Virtual Reality

A VR simulation of the proposed university hospital and the surrounding environment has been developed using Safe-VR. Due to the high number of polygons and textures of the 3D CG model, the model had to be optimised so that a real-time rendering was possible at a high enough frame rate to achieve smooth navigation whilst still maintaining accuracy and realism. Therefore, the modelling environment was restricted to areas within a few hundred metres of the site and some of the larger textures were repeated where possible and scaled down in size.

Since the simulation would involve users navigating around the environment close to the surface, roads, kerbs and pavements were added to the model. Other detailed features included fences, street lights and road signs. The geometry of the vegetation models was also modified from single plane objects to double plane objects with the planes intersecting one another at right angles (figure 6.27). This was necessary since Safe-VR does not support the use of billboards (planar objects which can be rotated to face the user).



Figure 6.27: Double plane tree model¹⁴⁷.

The models were exported using a DirectX “.x” file format and imported into Safe-VR. Simulation scripts were developed which enabled the user to switch between the pre-development and post-development scenarios, jump to critical viewpoints, and show photographs and photomontages from various viewpoints. Figure 6.28 shows the view from critical viewpoint one within the Safe-VR simulation.

Using the results from the percentage view analysis that was performed on the new university hospital from the local residential tower block, the user is also able to switch between the regular tower block texture map, the percentage decrease in vegetation tower block texture map and the percentage view of university hospital tower block texture map by double clicking with the mouse on the tower block (figure 6.29). The percentage view figures were added to the texture maps instead of using a key so that the results were clearer.

¹⁴⁷ Image from a 3D model created by the author (March 2003).

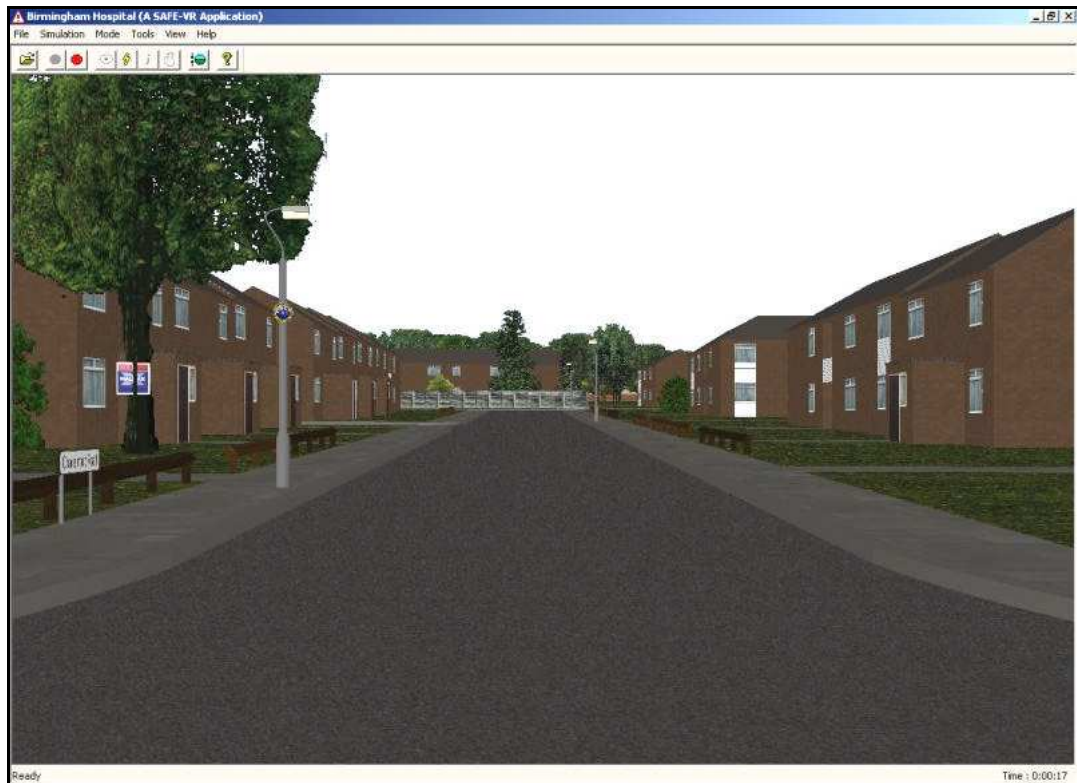


Figure 6.28: Safe-VR simulation view from critical viewpoint one¹⁴⁸.

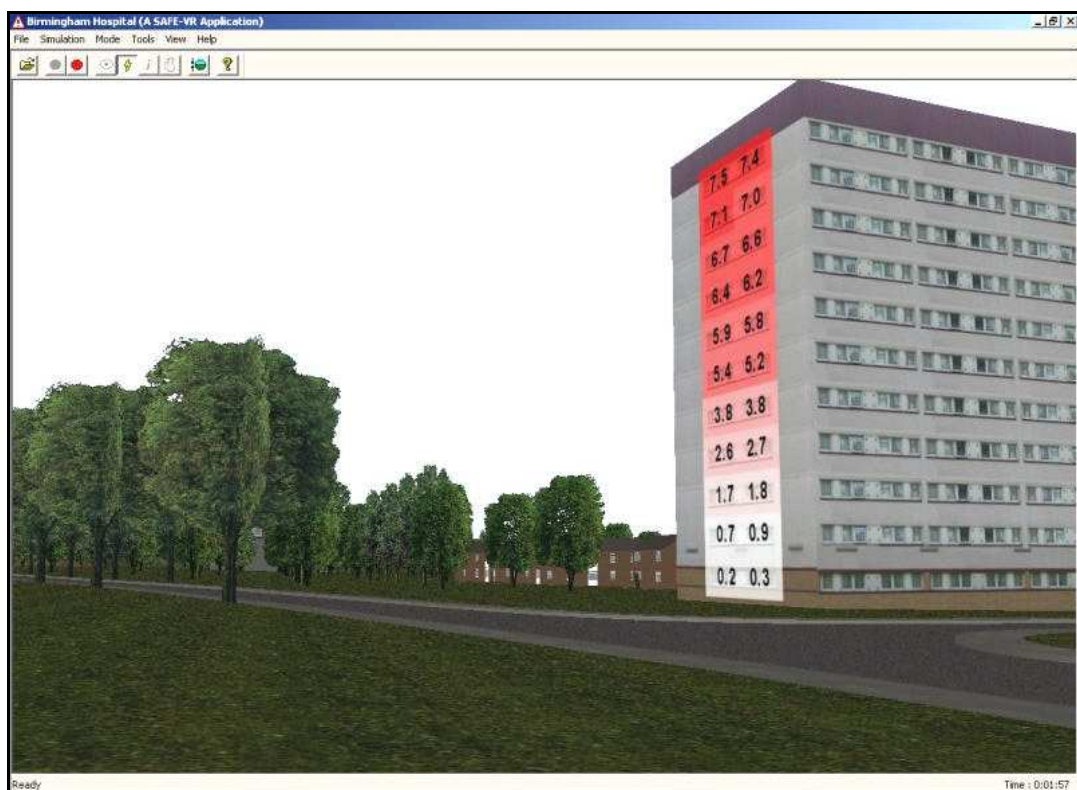


Figure 6.29: View of the tower block showing the percentage view of the proposed hospital¹⁴⁹.

¹⁴⁸ Screenshot and VR environment by the author (June 2000).

¹⁴⁹ Screenshot and VR environment by the author (June 2000).

6.3.4 Relocation of the Psychiatric Hospital

6.3.4.1 Modelling

The psychiatric hospital 3D CG model was created by modifying the proposed university hospital model. Changes included the addition of the psychiatric hospital and the addition and removal of vegetation. The surface model remained the same geometrically, but the surface texture map had to be modified using Paint Shop Pro.

CAD data was supplied for the geometry and position of the psychiatric hospital, but no data was available to illustrate the colour and texture of the hospital. Therefore, under guidance from Bابتie Group, the hospital was textured with a simple brown brick texture, semi-transparent glass and a grey roof. The 3D model of the psychiatric hospital was basic since the architectural plans had not been finalised during the development of the model. Figure 6.30 shows a rendered image of the psychiatric hospital.

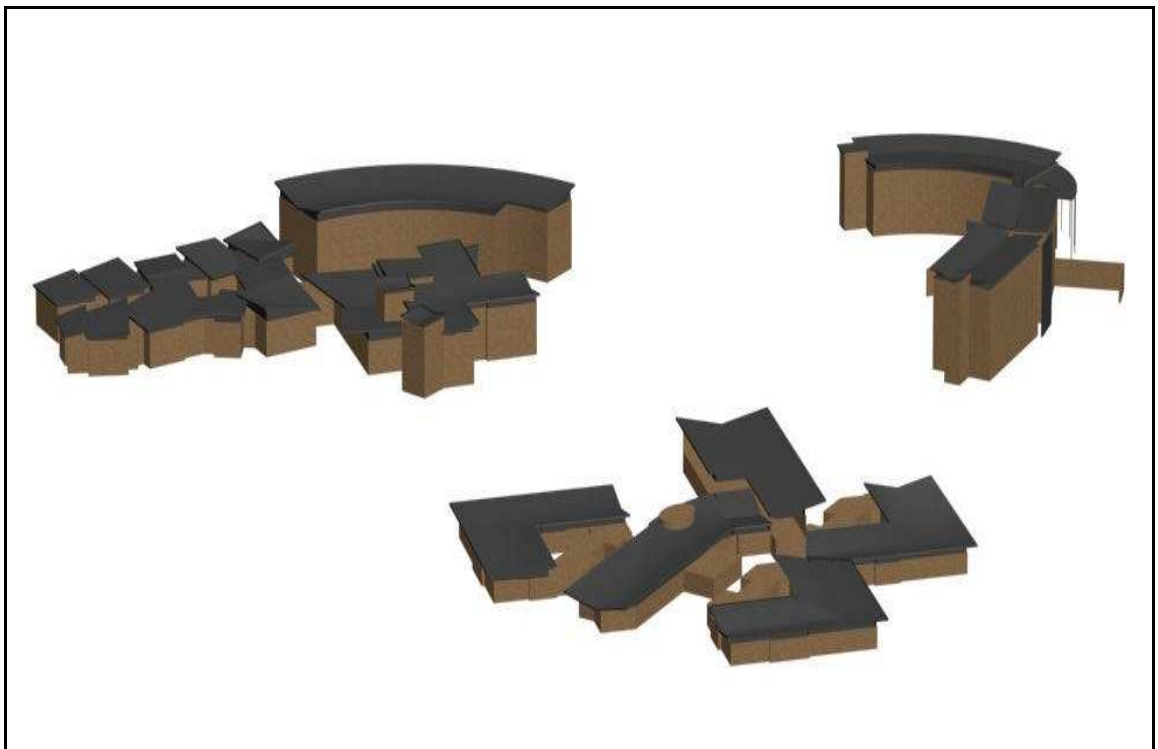


Figure 6.30: Rendered image of the new psychiatric hospital¹⁵⁰.

¹⁵⁰ 3D model created by the author (May 2000) using CAD data from Bابتie Group (2000c).



Figure 6.31: Rendered image of the psychiatric hospital site pre-development¹⁵¹.



Figure 6.32: Rendered image of the psychiatric hospital site post-development¹⁵².

¹⁵¹ Rendered image from a 3D model created by the author (May 2000).

¹⁵² Rendered image from a 3D model created by the author (May 2000).

Due to the new location of the psychiatric hospital, vegetation had to be removed and for the proposed landscaping, vegetation also had to be added. Babbie Group supplied CAD data on the location, size and species of the vegetation.

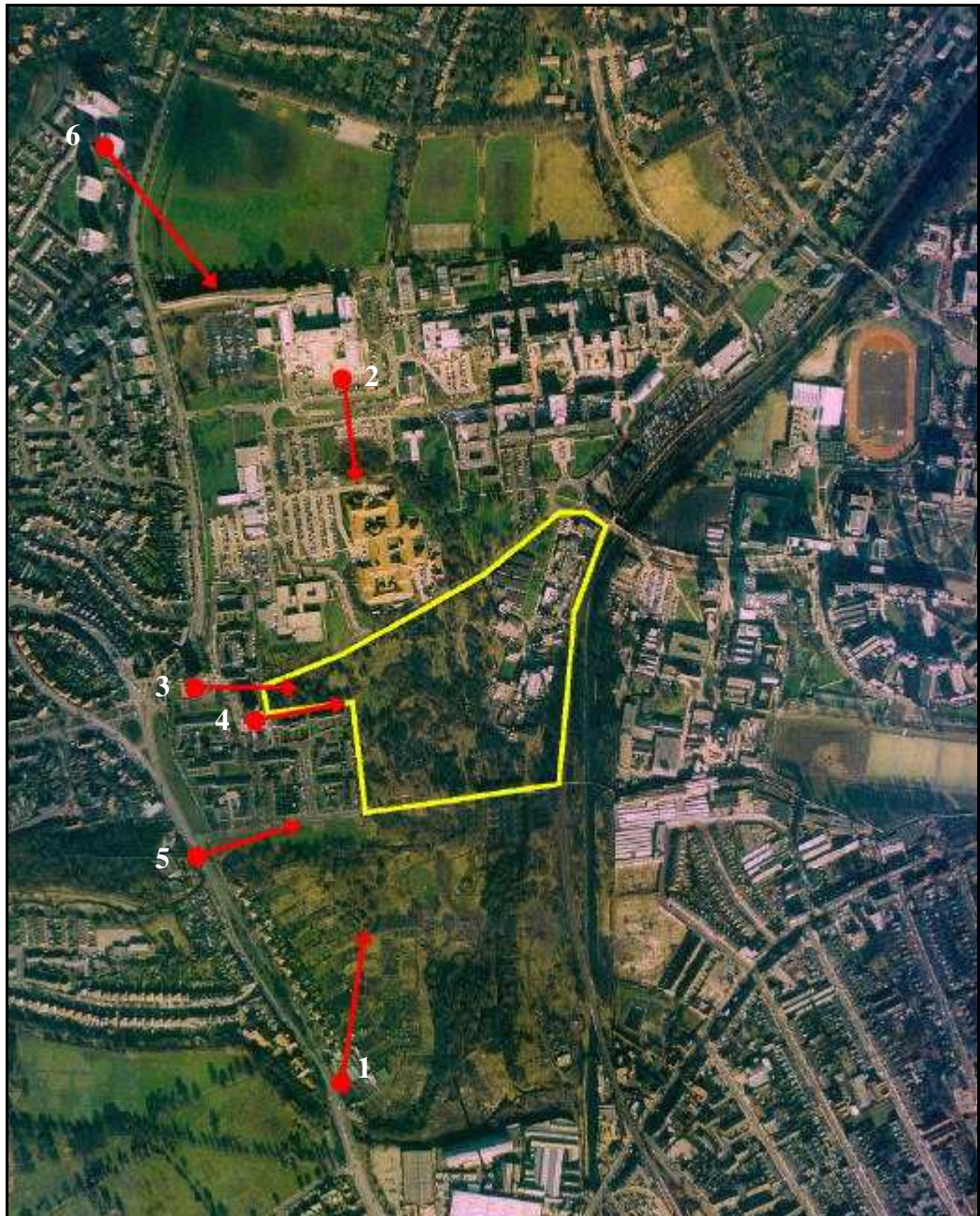


Figure 6.33: Location and direction of critical viewpoints¹⁵³.

Similar to the new university hospital model, it was possible to switch between pre-

¹⁵³ Image modified by the author (March 2003) from an aerial image from Babbie Group (2000c).

development and post-development models by hiding or showing various features of the 3D environment within 3D Studio MAX. Figures 6.31 and 6.32 show rendered images of the pre-development and post-development psychiatric hospital models respectively.

Six critical viewpoints were defined by Babtie Group and virtual cameras were set up within the 3D model at each of their locations looking towards the proposed psychiatric hospital site. Figure 6.33 shows the location and direction of these critical viewpoints.

6.3.4.2 Visualisations

Rendered images were produced for each of the critical viewpoints for both the pre-development and post-development models. Unlike the new university hospital development, photomontages were not produced since photographs from the critical viewpoints were unavailable.



Figure 6.34: Rendered image of the psychiatric hospital site post-development¹⁵⁴.

¹⁵⁴ Rendered image from a 3D model created by the author (May 2000).

Figure 6.34 shows the rendered image from critical viewpoint three (from a local residential tower block) showing what the environment will look like with the psychiatric hospital in place. Appendix 7 shows the rendered images for all six critical viewpoints for the pre-development and post-development models.

Similar to the new university hospital development, animations showing the pre-development and post-development models were also produced. These animations can be found on the CD-ROM in appendix 9.

6.3.4.3 Percentage View Change Analysis

For each critical viewpoint, the percentage view change in vegetation and the percentage view of the new psychiatric hospital was determined. The pre-development and post-development 3D CG models were colour modified so that vegetation was green and the new psychiatric hospital red. All other features within the model were coloured black. The view from each critical viewpoint was then rendered for both models with an aspect ratio of 4:3 and at a resolution of 800 by 600. Figure 6.35 shows the colour modified rendered image from critical viewpoint three after the relocation and development of the psychiatric hospital. The images were passed through the Bitmap Colour Counter utility for analysis and the results formatted to produce table 6.5.

Critical viewpoints three and four resulted in the largest decrease in view of vegetation and the highest percentage view taken up by the psychiatric hospital. These results are not unexpected since critical viewpoints three and four are from top floor views from tower blocks located adjacent to the proposed site. It was also found that critical viewpoint six would hardly be affected by the relocation of the psychiatric hospital and this is because the Women's Hospital shields the view and it is located far away from the site.

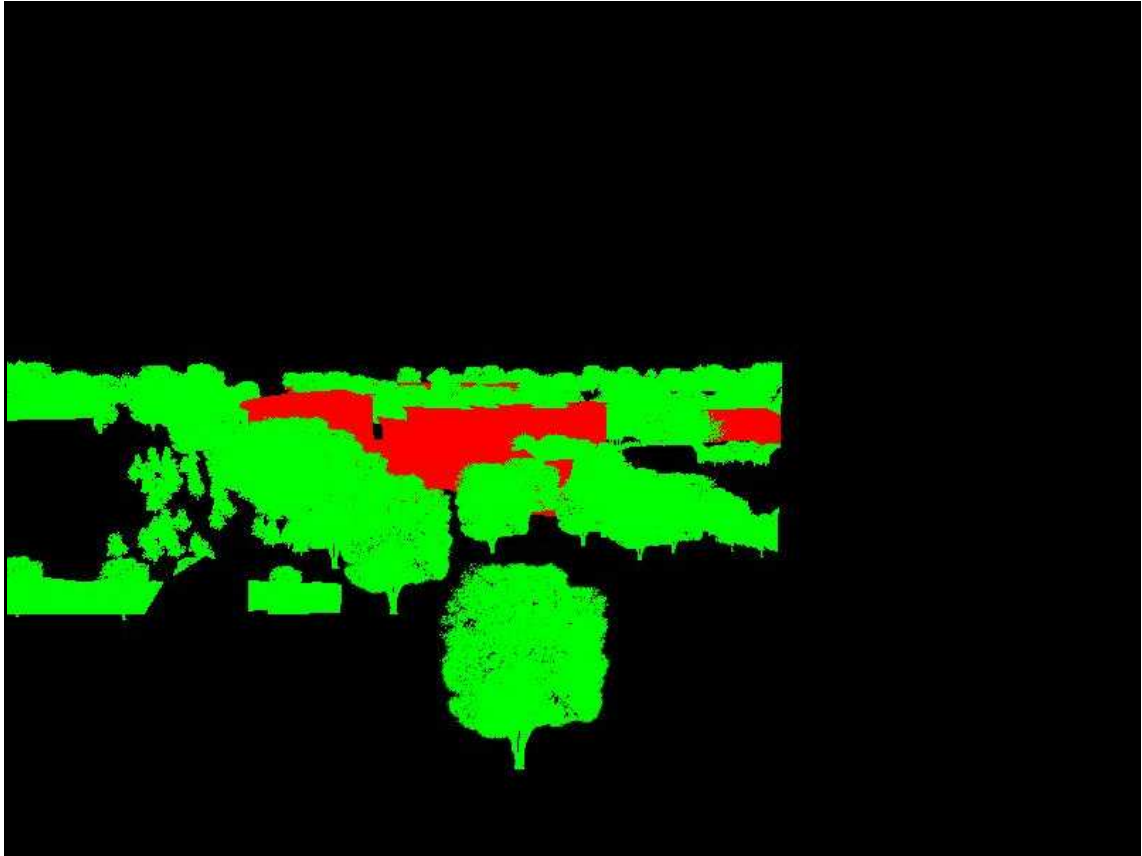


Figure 6.35: Colour modified image from critical viewpoint three showing the psychiatric hospital¹⁵⁵.

Critical Viewpoint	Percentage View of Vegetation			Percentage View of Psychiatric Hospital
	Pre-development	Post-development	Change	
1	9.05	8.70	-0.35	0.32
2	8.14	8.03	-0.11	0.13
3	14.92	12.85	-2.06	1.98
4	30.27	24.24	-6.03	9.19
5	8.29	7.65	-0.64	0.45
6	16.37	16.31	-0.06	0.06

Table 6.5: Percentage view of vegetation and psychiatric hospital from the critical viewpoints.

¹⁵⁵ Image from a 3D model created by the author (May 2000) and a photograph by Babbie Group (2000c).

A percentage view analysis was also performed on the nearby residential tower block that was used to assess the visual impact of the new university hospital. This time, however, the windows used for analysis were located on the east side of the building which faces the site. The tower block consists of eleven floors, with six windows on each floor, totalling 66 windows for analysis.

For each window, a rendered image was produced using the colour modified pre-development and post-development models, and using Animation Shop an uncompressed animation was produced for each model. The animation was then passed through the Bitmap Colour Counter, the results saved to file and table 6.6 produced.

The tower block windows texture map was again shaded according to the percentage change in view of vegetation and psychiatric hospital with the darker shades representing a higher change. Perspective views of the tower block were then rendered with the new tower block texture maps applied (figures 6.36 and 6.37).

The results showed a decrease in the percentage view of vegetation for the upper windows of the tower block and a general increase in view of vegetation for the lower windows. Also, the higher up the window, the higher the percentage view of the new development. The percentage view taken up by the psychiatric hospital from the ground floor windows ranged from 0.27 to 1.17, whilst the percentage view taken up by the psychiatric hospital from the top floor windows ranged from 13.99 to 16.97 percent.

Window	Percentage Decrease in Vegetation	Percentage View of Psychiatric Hospital	Window	Percentage Decrease in Vegetation	Percentage View of Psychiatric Hospital
1	10.60	13.99	34	3.31	7.05
2	11.72	14.93	35	3.37	6.70
3	13.00	15.86	36	3.95	6.57
4	13.12	16.22	37	-1.06	5.15
5	13.73	16.57	38	0.49	4.97
6	14.36	16.97	39	1.74	5.10
7	8.69	12.64	40	2.46	4.78
8	9.74	13.42	41	1.73	4.24
9	11.30	14.35	42	1.69	3.87
10	11.72	14.68	43	-1.51	3.22
11	12.33	14.94	44	-0.44	2.92
12	13.05	15.26	45	0.01	2.79
13	6.67	11.28	46	0.06	2.28
14	7.55	11.84	47	-0.34	1.62
15	9.27	12.74	48	-0.18	1.11
16	9.67	12.99	49	-1.19	1.61
17	10.07	13.16	50	-0.51	1.35
18	10.60	13.41	51	-0.84	0.84
19	4.61	9.88	52	-0.37	0.57
20	5.00	10.25	53	-1.13	0.14
21	6.36	11.05	54	-0.70	0.06
22	6.65	11.19	55	-0.87	0.96
23	6.95	11.24	56	-0.36	0.65
24	7.45	11.39	57	-0.50	0.13
25	2.62	8.43	58	0.13	0.14
26	3.28	8.61	59	-0.60	0.21
27	4.27	9.25	60	-0.40	0.39
28	4.32	9.24	61	0.04	0.98
29	4.41	9.05	62	0.55	1.17
30	5.02	9.09	63	-1.46	0.90
31	0.61	6.80	64	-2.99	0.27
32	1.99	6.81	65	-0.28	0.97
33	2.91	7.25	66	-0.50	0.51

Table 6.6: Results of the percentage view analysis for the tower block (windows are ordered starting at the top left window, working across and then down).

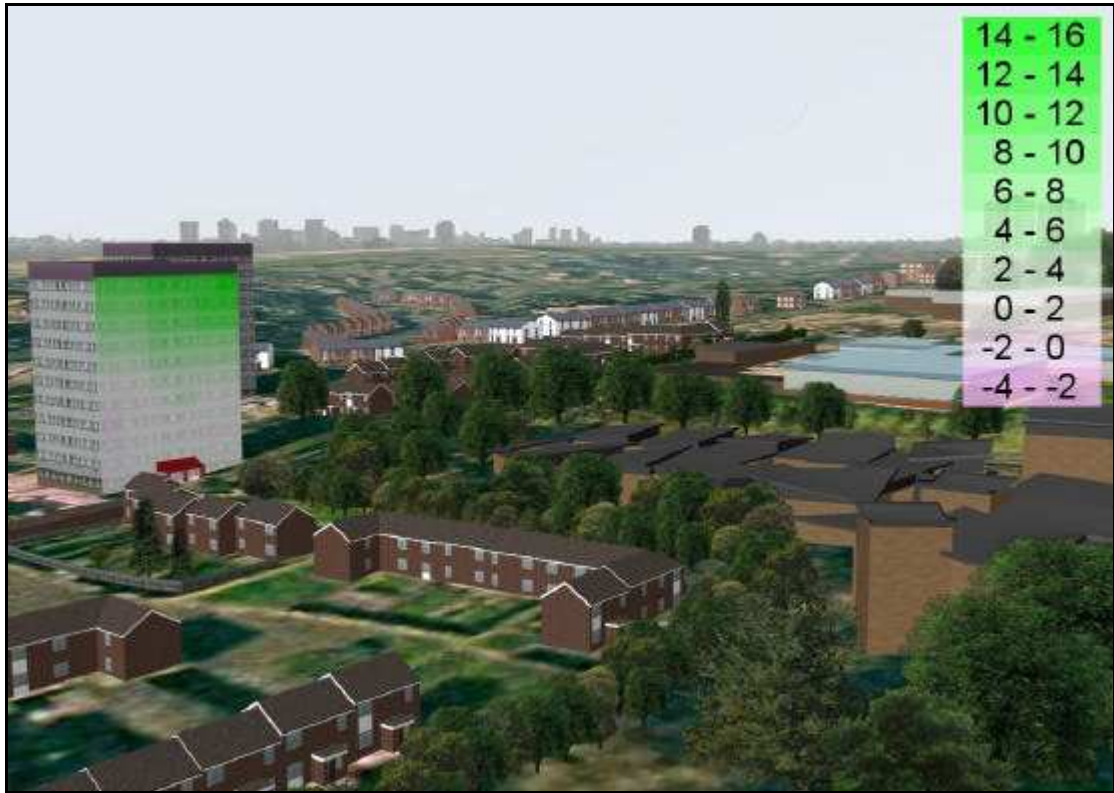


Figure 6.36: View of the tower block showing the percentage view decrease in vegetation¹⁵⁶.

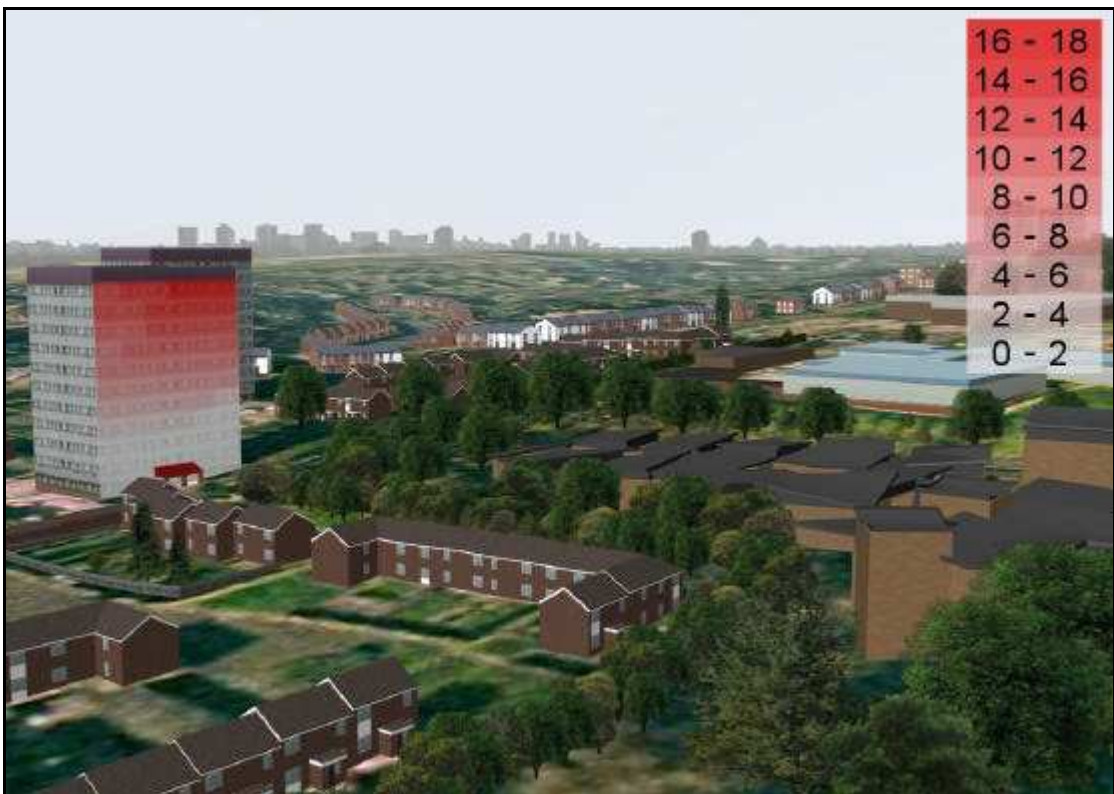


Figure 6.37: View of the tower block showing the percentage view of the psychiatric hospital¹⁵⁷.

¹⁵⁶ 3D model created by the author (May 2000).

¹⁵⁷ 3D model created by the author (May 2000).

6.3.5 Analysis

A number of visualisations, in the form of static rendered images, animations and photomontages, percentage view change analyses and VR techniques have been performed for a proposed university hospital and a relocated psychiatric hospital in order to assess their potential visual impact on the environment. Over two square kilometres of land, buildings and vegetation has been modelled in 3D using CG techniques.

The project was split into two sub-projects: the development of the new university hospital, and the relocation and development of the psychiatric hospital. For each sub-project, critical viewpoints were identified by Babtie Group. For each of these viewpoints, rendered static images were produced and where possible, photomontages created using photographs taken by Babtie Group. A percentage view analysis was then performed for each critical viewpoint and a local tower block and the percentage view change in vegetation and percentage view of new development determined. It was discovered that the viewpoints which showed the highest visual change were either located adjacent to the site or from the upper floors of the local tower blocks. In general, for the majority of the critical viewpoints identified by Babtie Group, the percentage view changes due to the proposed developments were small, and much of this can be attributed to good landscaping and screening proposals.

Safe-VR was used to create a VR simulation of the proposed university hospital site and its surrounding environment. The simulation allowed the user unrestricted views of the environment and could show pre-development and post-development scenarios. The use of hot keys also allowed the user to navigate directly to defined critical viewpoints and display photographs, photomontages and FVIs from that viewpoint. The results from the percentage view analysis on the new university hospital from the tower block were used in the VR simulation to graphically display the percentage view decrease of vegetation and percentage view of new university hospital by double clicking on the tower block. This enabled some

quantitative analysis to be incorporated with an otherwise qualitative VIA technique. The disadvantage with the Safe-VR simulation is that the model had to be optimised to enable the simulation to be rendered smoothly in real-time. This remodelling will have had a small negative effect on the accuracy of the technique. However, with the ever increasing power of 3D graphics cards, in the future the number of faces and number and size of texture maps can be increased to produce accurate and realistic VR simulations that can render in real-time.

Babtie Group were pleased with the visualisations of the hospitals, and the percentage view change analysis of the psychiatric hospital was submitted as part of their EIS for the project. Babtie Group were positive about the new percentage view change technique and regarded it above many over traditional VIA techniques.

6.4 Bellmoor Quarry, Tilm South

6.4.1 Introduction

This was originally a project that AIMS Research, at the University of Nottingham, undertook in 1993. AIMS Research were asked to produce a number of stills and animations as part of a planning application submitted by Tarmac Quarry Products Limited for the extraction of sand and gravel and then a phased restoration to agriculture, forestry and water at Tilm South, a small hamlet in Nottinghamshire. The original model produced by AIMS Research was very basic due to the primitive 3D modelling software packages and computer hardware that were available at the time. However, technology has moved on and current hardware and software is more advanced (see appendices 1 and 2).

The Tilm South environment has been recently remodelled, using 3D Studio MAX, so that it can be used as a case study in order to demonstrate some of the new and enhanced VIA techniques that have been developed during this research. Three 3D CG models of Tilm South and its surrounding environment have been built. The first model is the pre-development model, which

represents existing conditions (in 1993), the second model is the during quarrying model, and the third model is the post-development model, which represents the environment after reclamation. In order to assess the visual impact of the quarry at the worst case scenario, the stage where quarrying was closest to Tiln South was selected. The techniques which have been used to assess the visual impact of the quarry include static and animated visualisations, FVIs, percentage view change calculations and VR. The effect of seasonal variation on vegetation has also been assessed in this case study.

6.4.2 Data Acquisition

The data that was originally supplied to AIMS Research was available for the author to use and included:

- ?? A printed aerial photograph of the proposed site (figure 6.38).
- ?? Printed CAD data of existing and proposed developments including vegetation data and contour data (figure 6.39).
- ?? Environmental and written statements.
- ?? Sketched drawings of Tiln South buildings.

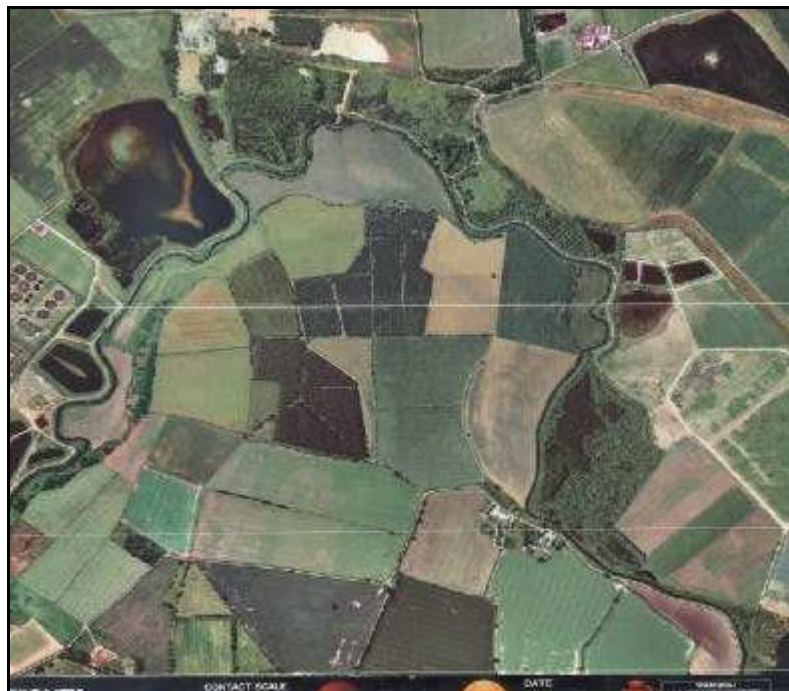


Figure 6.38: Aerial photograph of proposed site situated near Tiln South¹⁵⁸.

¹⁵⁸ Photograph supplied by Tarmac Quarry Products Limited (1993).

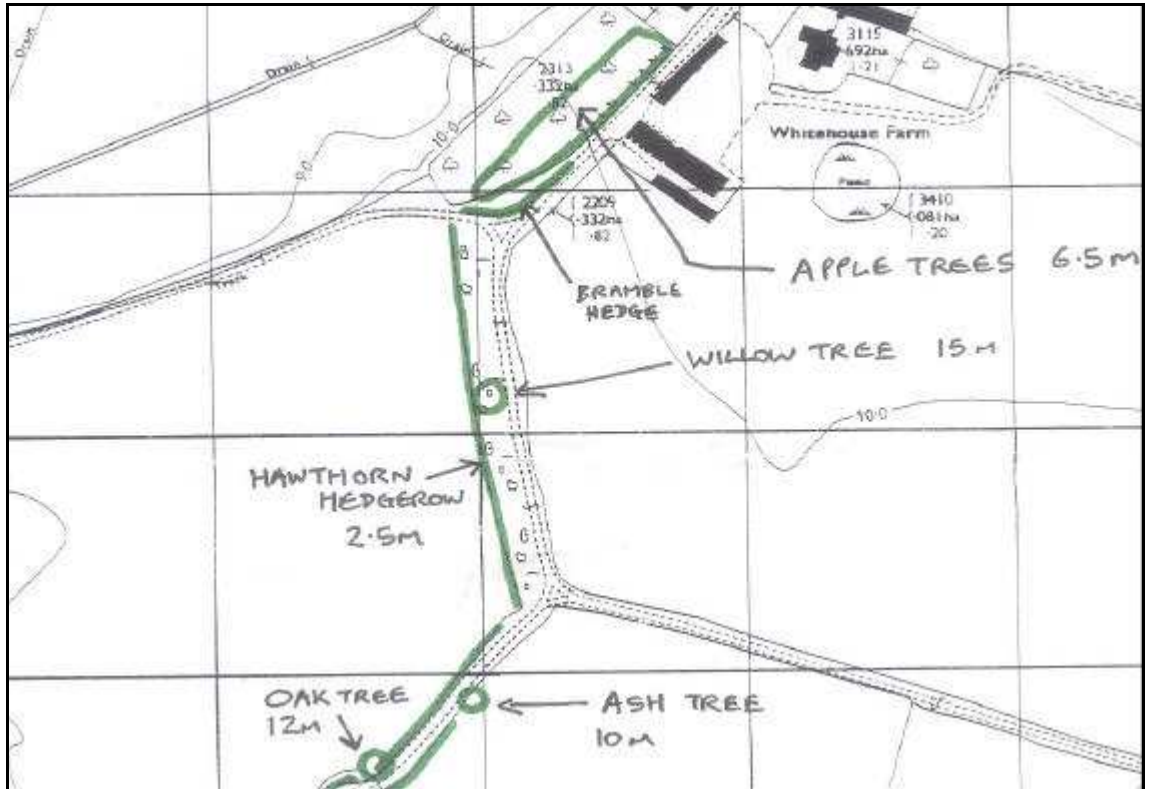


Figure 6.39: Pre-development CAD data of Tiln South in an annotated printed format¹⁵⁹.

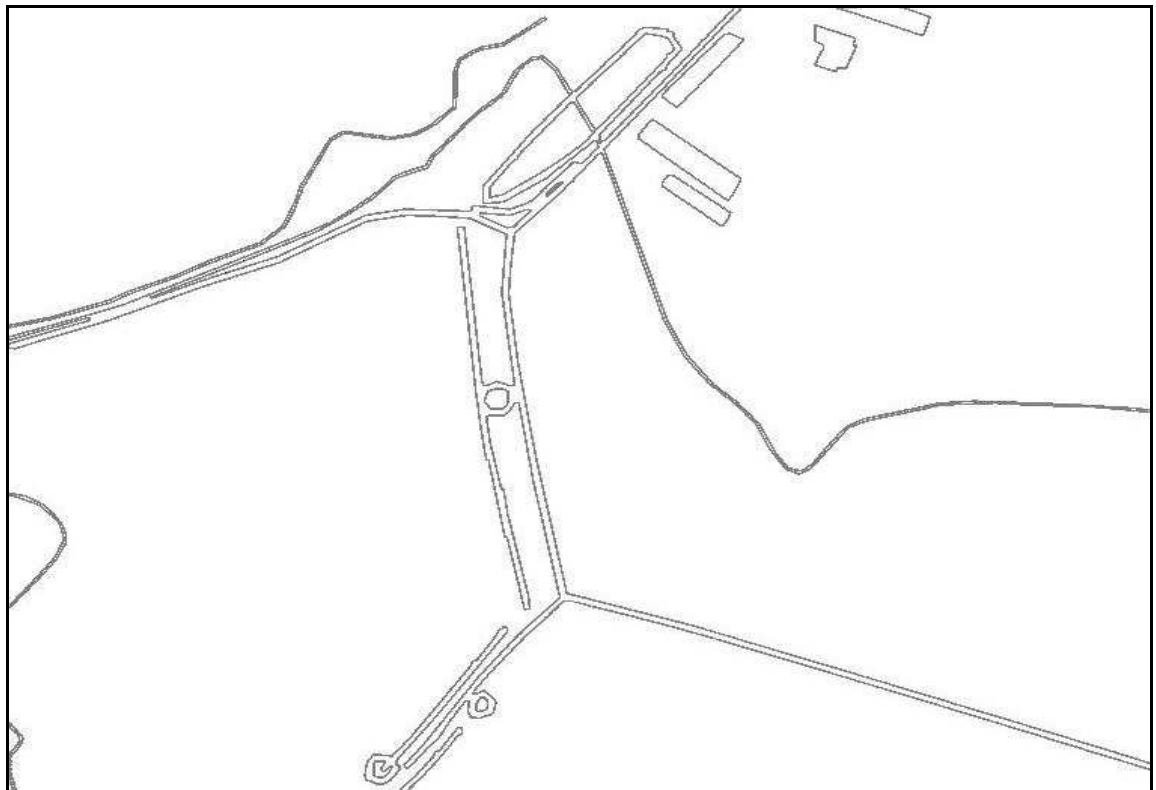


Figure 6.40: Contour and land use splines generated from printed CAD data (as shown in figure 6.39)¹⁶⁰.

¹⁵⁹ Image by the author (March 2003) from CAD data supplied by Tarmac Quarry Products Limited (1993).

¹⁶⁰ Image and model by the author (March 2003) from CAD data supplied by Tarmac Quarry Products Limited (1993).

Using a flatbed scanner, the aerial photograph was digitally scanned and saved as a high resolution raster image. Using Paint Shop Pro, the aerial image was then “touched up” in order to hide white crease marks where it had been folded. The printed CAD data for the existing, quarrying and restoration phases were also scanned and saved as raster images which were then converted to vector images using Corel OCR-TRACE and exported using the “DXF” file format so that they could be imported into 3D Studio MAX as splines (figure 6.40). The CAD spline data was then manipulated to separate contour data from land use data.

6.4.3 Modelling

This case study consists of three individual models which represent three different development stages in the quarry life-cycle, which are: pre-development model, during quarrying model and post-development model. Therefore this section has been split up into three sub-sections each describing the modelling process for each separate development stage.

6.4.3.1 Pre-Development Model

The contour splines for the pre-development model (figure 6.41), which were vectorised from the CAD data, were converted into a DEM using the “terrain” function and textured with the aerial bitmap image of the existing ground surface (figure 6.42).

The Tiln South buildings were modelled using a combination of primitive objects and extruded splines based on some hand drawn sketches that were originally produced by AIMS Research. The static images and animations, which were previously produced by AIMS Research, were used to obtain information regarding the colour and texture of the various buildings. The buildings were then placed on the ground surface and positioned according to the vectorised CAD data.

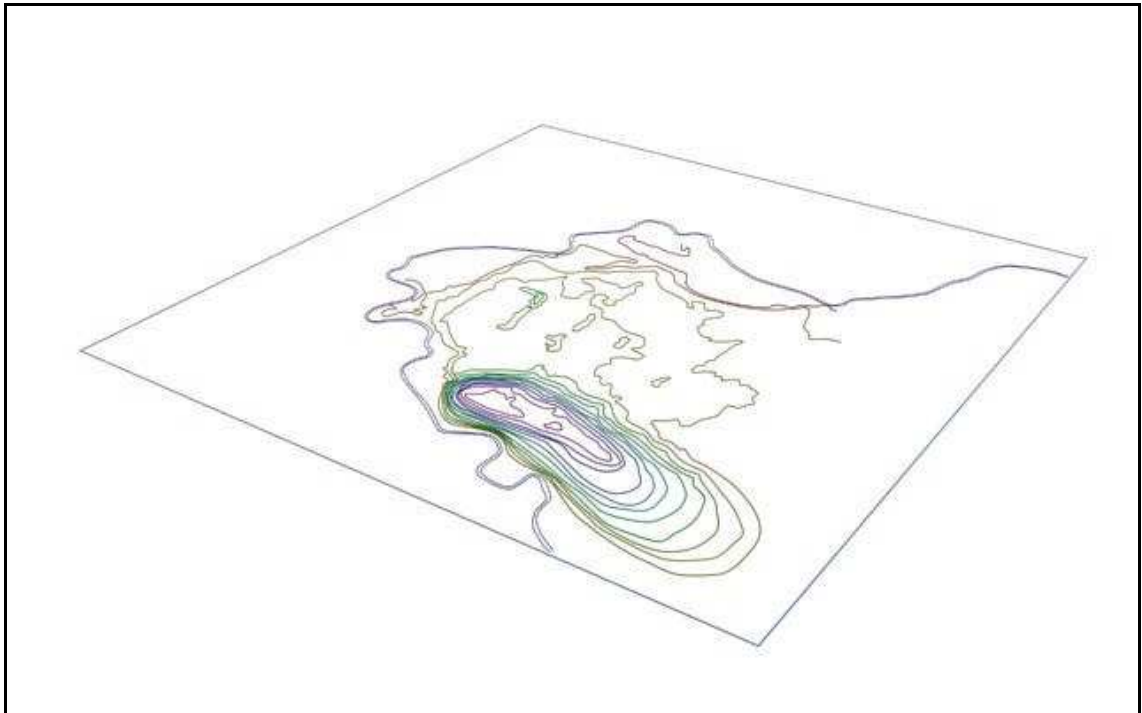


Figure 6.41: Contour splines for the pre-development model¹⁶¹.



Figure 6.42: 3D textured ground surface of the pre-development model¹⁶².

¹⁶¹ Image from a 3D model created by the author (June 2001).

¹⁶² Image from a 3D model created by the author (June 2001).

The CAD data indicated that there were a number of electricity pylons situated within the modelling environment. Using data obtained from the original AIMS Research model, the pylons were created using a number of box primitives that were modified to form the general shape of a pylon (figure 6.43a). Instead of modelling each strut within the pylon, opacity maps, shown in figure 6.43b, were used which gave the same visual result. This modelling technique enabled the pylons to be created quickly and with a low number of polygons, which enhanced the efficiency of the overall model. Figure 6.43c shows a rendered image of one of the pylon models.

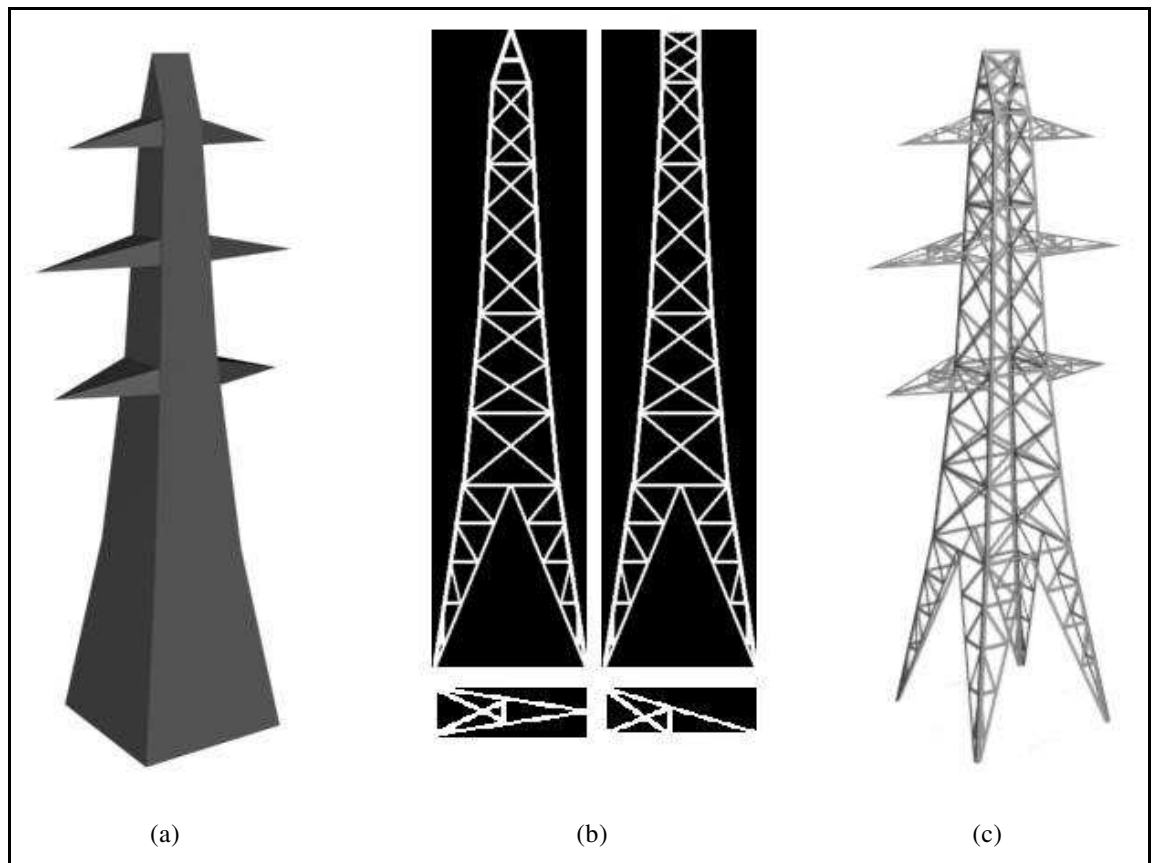


Figure 6.43: Modelling process of the electricity pylon¹⁶³.

The annotated CAD data provided information on the location and height of both individual and groups of trees and hedges. Therefore, using the splines (which were derived from vectorising the CAD data) as boundaries, individual and groups of trees were created using the Forest Pro

¹⁶³ Images from a 3D model created by the author (June 2001).

plug-in (described in more detail in appendix 1). The tree and shrub models were sized and textured according to the information provided by the CAD data annotations (as shown in figure 6.39). The hedges were modelled using box primitives combined with planes which protruded from the boxes to give the hedge models some irregularity (figure 6.44).

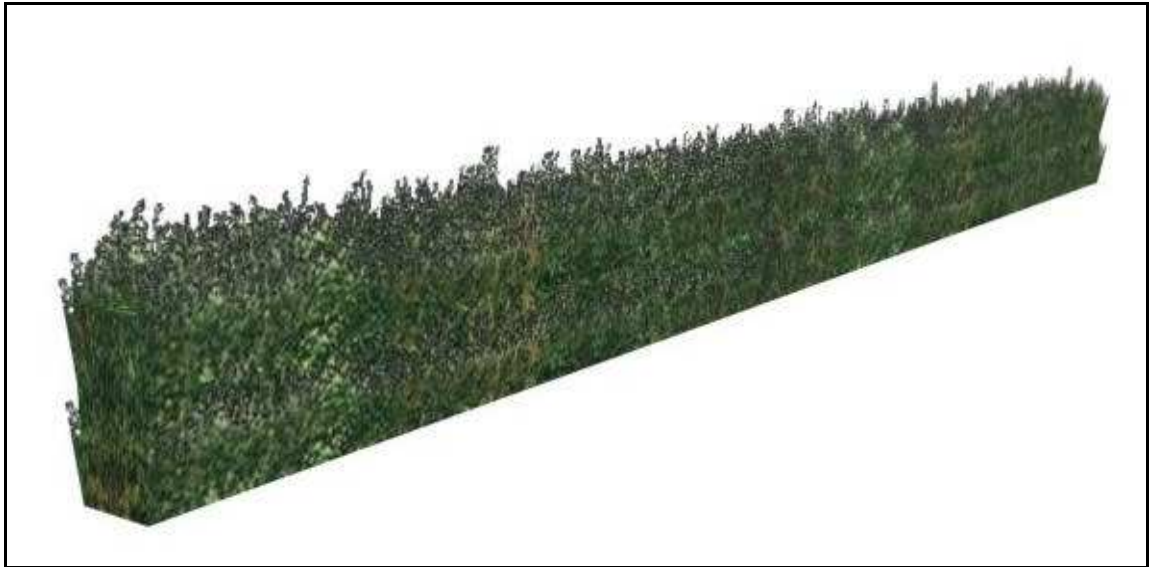


Figure 6.44: Rendered image of a 3D hedge model¹⁶⁴.



Figure 6.45: Reflection and bump map applied to an extruded spline to simulate the river¹⁶⁵.

¹⁶⁴ Image from a 3D model created by the author (June 2001).

The model also included a river which passes by Tiln South and the proposed quarry site. The river was modelled using extruded splines which followed the path of the river. To give the river model a realistic appearance, a mirror effect was added to reflect any surrounding objects and a bump map applied to give a ripple effect (figure 6.45).

Due to the limited resolution of the aerial photograph, the road which passes through Tiln South was not easily legible from views which were close to the road (figure 6.46a). Therefore a road model was added to the environment using extruded splines which were aligned to the surface model and textured with a road image. To roughen the edges of the road an opacity map was added, which had the effect of blending the edges of the road into the ground surface model (figure 6.46b).



Figure 6.46: Rendered images of the model with an illegible road (a) and modelled road (b)¹⁶⁶.

To finish the model, a background was added in the form of a hemisphere which surrounded the entire model and texture mapped with a sky image. Figure 6.47 shows a rendered image of the finished pre-development model, which shows the proposed quarry site in the centre of the image, with the hamlet of Tiln South shown at the bottom.

¹⁶⁵ Image from a 3D model created by the author (June 2001).

¹⁶⁶ Image from a 3D model created by the author (June 2001).



Figure 6.47: Rendered image of Tiln South and proposed quarry site pre-development¹⁶⁷.

6.4.3.2 During Quarrying Model

The during quarrying model was created in very much the same way as the pre-development model using a number of similar modelling techniques. Features such as the Tiln South buildings, the road, the river and the background, which remained unchanged through the quarry life-cycle, were copied across from the pre-development model into the during quarrying model. Some of the trees and hedges in the pre-development model were also copied across since they also remained unchanged.

The terrain had to be re-modelled using the vectorised CAD data of the quarrying phase. The terrain also had to be re-textured using a modified version of the aerial bitmap image that was used in the pre-development model. This was achieved by using Paint Shop Pro to overlay sand and gravel textures, as illustrated in the CAD plans provided, onto a copy of the original aerial image (figure 6.48).

¹⁶⁷ Image from a 3D model created by the author (June 2001).



Figure 6.48: Surface texture for the during quarrying model¹⁶⁸.

Vegetative screening also had to be added to the model which consisted of groups of trees, scattered shrubs and additional hedges. These were created using the same techniques as described in the modelling section for the pre-development model. Figure 6.49 shows a rendered image of the finished during quarrying model which shows one of the quarry pits in the centre of the image just above the hamlet of Tiln South.

¹⁶⁸ Adapted by the author (June 2001) from an aerial photograph supplied by Tarmac Quarry Products Limited (1993).



Figure 6.49: Rendered image of Tiln South and proposed quarry site during quarrying¹⁶⁹.

6.4.3.3 Post-development Model

Modelling the post-development model consisted of using and modifying some of the features within the pre-development and during quarrying models and adding some new features. As with the during quarrying model, the terrain had to be re-modelled and re-textured to allow for a new lake and some fields. Figure 6.50 shows the post-development surface texture map which was modified from the original aerial image.

Vegetation had to be added or removed in specific, defined locations. Two features which also had to be added were a lake and a fence that surrounds the lake. The lake was modelled by extruding a closed spline and textured using the existing river texture. The fence was modelled using a number of box primitives and textured with a bitmap image of a fence. Figure 6.51 shows a rendered image of the finished post-development model.

¹⁶⁹ Image from a 3D model created by the author (June 2001).



Figure 6.50: Surface texture for the post-development model¹⁷⁰.



Figure 6.51: Rendered image of Tilm South and proposed quarry site post-development¹⁷¹.

¹⁷⁰ Adapted by the author (June 2001) from an aerial photograph supplied by Tarmac Quarry Products Limited (1993).

6.4.4 Visualisations using Rendered Images and Animations

For each of the four residential properties in Tilm South, a critical viewpoint was identified (figure 6.52). The critical viewpoints were chosen in order to represent a worst case scenario which consisted of views from elevated windows which were unobstructed by screening.

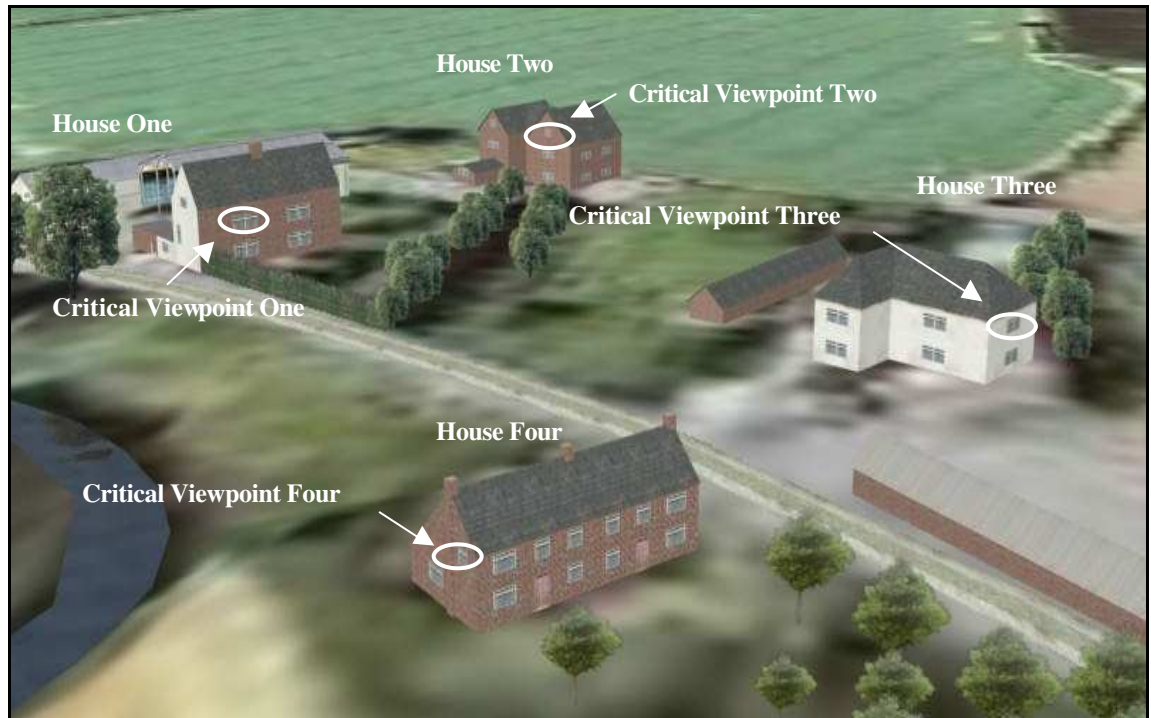


Figure 6.52: Location of critical viewpoints identified by white ring¹⁷².

For each of the three development stages (pre-development, during quarrying and post-development), static images were rendered from each of the four critical viewpoints, looking towards the proposed quarry site. Figures 6.53, 6.54 and 6.55 show the rendered images from critical viewpoint one for the three development stages respectively. Appendix 8 shows the rendered images from all four critical viewpoints.

¹⁷¹ Image from a 3D model created by the author (June 2001).

¹⁷² Image from a 3D model created by the author (June 2001).



Figure 6.53: Critical viewpoint one pre-development¹⁷³.



Figure 6.54: Critical viewpoint one during quarrying¹⁷⁴.

¹⁷³ Images from a 3D model created by the author (June 2001).

¹⁷⁴ Images from a 3D model created by the author (June 2001).



Figure 6.55: Critical viewpoint one post-development¹⁷⁵.

Simple animations for each of the three development stages were also produced, consisting of a viewpoint moving around the perimeter of the proposed quarry site and focusing on the centre of the site. This was achieved by linking a virtual camera to a circular spline which was modelled above and around the quarry site perimeter. The camera target was then positioned at the centre of the proposed quarry site and the animation rendered over a 375 frame period at 25 frames per second in order to produce a 15 second animation. The three animations can be found on the CD-ROM in appendix 9.

6.4.5 Fields of Visual Influence

Using the same four critical viewpoints that were previously identified, four reflective FVIs were produced. Using the guidelines set out in chapter 5, an omni light was placed at the location of critical viewpoint one. All the models were then textured with a basic white colour

¹⁷⁵ Images from a 3D model created by the author (June 2001).

whilst leaving any opacity maps intact. With all other lights turned off, the plan view of the model was rendered resulting in a black and white FVI, with the white regions representing areas which can be seen from critical viewpoint one (figure 6.56). This was performed for each of the four critical viewpoints for each of the three development stages, resulting in a total of twelve black and white FVIs.

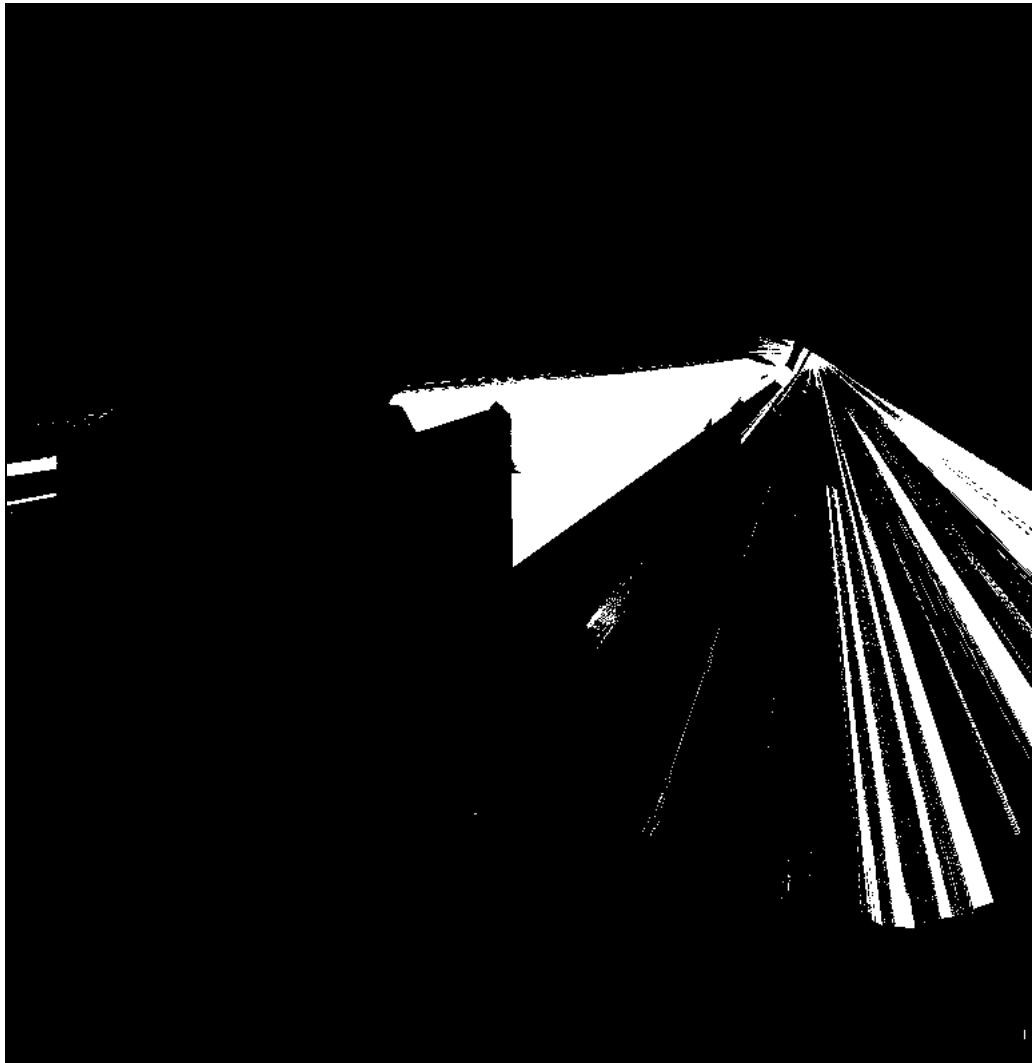


Figure 6.56: Black and white FVI for critical viewpoint one pre-development ¹⁷⁶.

Using Paint Shop Pro, the white areas of the FVIs were coloured red and made semi-transparent. These were then layered over the appropriate aerial images that were produced earlier during the initial modelling stages. Figure 6.57 shows the resulting FVI for critical

¹⁷⁶ Image by the author (June 2001).

viewpoint one in the pre-development model. The FVI clearly shows which areas can be seen from critical viewpoint one as indicated by the red shading. All twelve reflective FVIs are shown in appendix 8.



Figure 6.57: FVI for critical viewpoint one pre-development ¹⁷⁷.

In order to determine which areas of the proposed site can be seen from at least one of the critical viewpoints, a cumulative FVI was produced. Using Paint Shop Pro, the four FVIs for each critical viewpoint were combined, for each of the three development stages. By layering the individual FVIs over one another, areas of red which overlap one another produce a stronger

¹⁷⁷ Image by the author (June 2001).

shade of red. Therefore, areas which can be seen by all four critical viewpoints are coloured a strong red, while areas which can only be seen by one critical viewpoints are coloured a weak red. The perimeter of the proposed quarry site was also added to the images, indicated by a yellow line. Figures 6.58, 6.59 and 6.60 show cumulative FVIs for pre-development, during quarrying and post-development respectively.



Figure 6.58: Cumulative FVI for the pre-development model at Tilm South¹⁷⁸.

The cumulative FVI shown in figure 6.58 shows that a large portion of the proposed quarry site can be seen from the four critical viewpoints. If quarrying was performed with existing

¹⁷⁸ Image by the author (June 2001).

screening conditions then the houses at Tiln South would be able to see a large extent of the proposed quarry workings. However, vegetative screening in the form of hedges, trees and scattered shrubs has been proposed and the effect of this screening can be seen in figure 6.59.



Figure 6.59: Cumulative FVI for the quarrying phase of Bellmoor quarry¹⁷⁹.

Figure 6.59, the FVI representing areas of the quarry site that can be seen from the critical viewpoints during quarrying, shows that the existing and proposed screening combine to shield the viewpoints from the majority of the quarry workings. Areas which can be seen within the

¹⁷⁹ Image by the author (June 2001).

proposed site are predominately unworked. This is confirmed by the static images rendered from the critical viewpoints as described in the previous section which are shown in appendix 8.

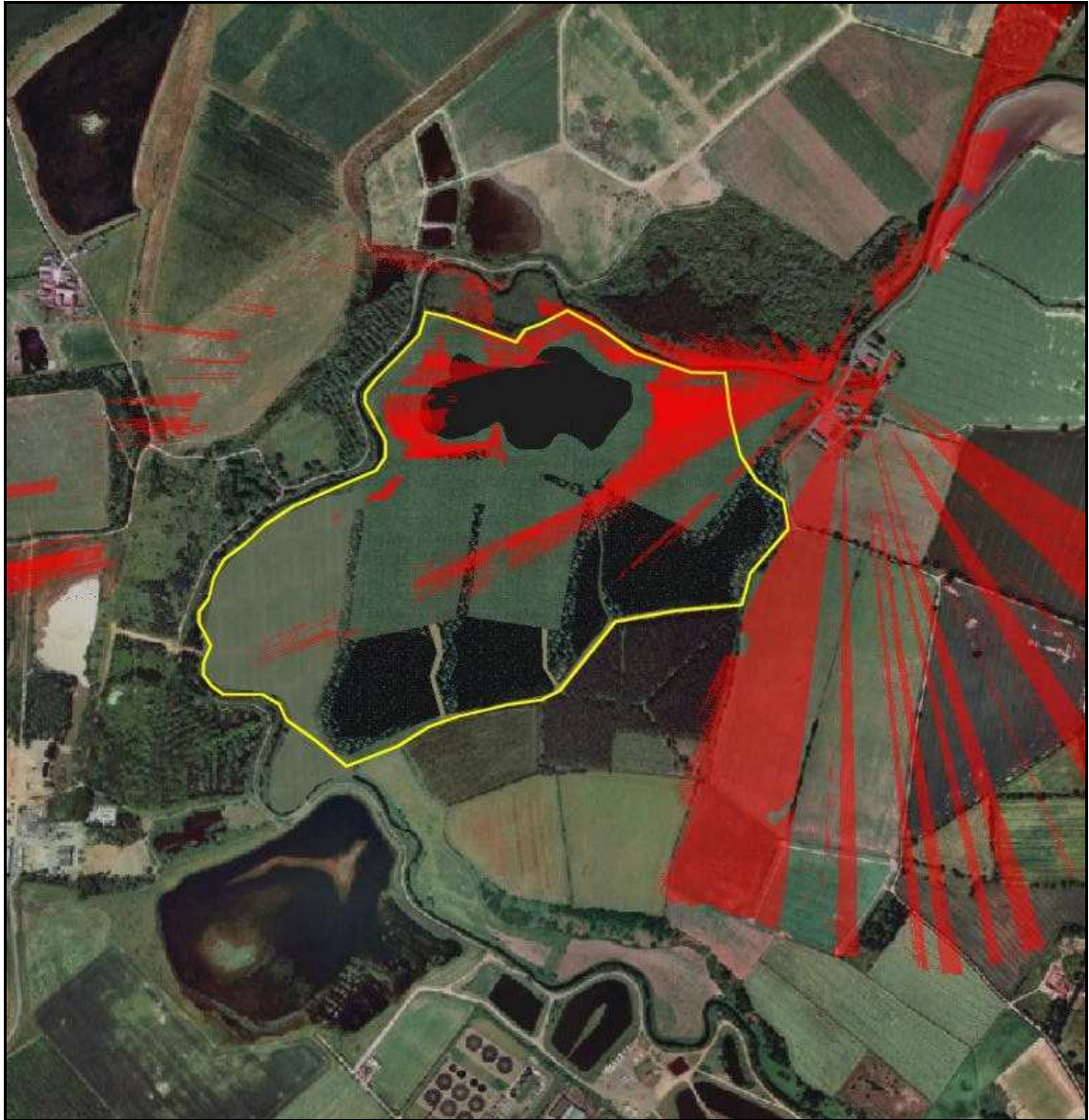


Figure 6.60: Cumulative FVI for the proposed reclamation of Bellmoor quarry¹⁸⁰.

Figure 6.60 shows the FVI representing areas of land which can be seen from the critical viewpoints when the proposed quarry site has been reclaimed. The majority of the visible areas consist of grassland, although a small proportion of the new lake and tree planting can also be seen. This is also confirmed by the static images rendered from the critical viewpoints.

¹⁸⁰ Image by the author (June 2001).

6.4.6 Percentage View Change Analysis

The percentage view change of various features within the Tiln South model were determined for each of the four critical viewpoints and for each of the three development stages. Using the technique described earlier in chapter 5, the three models were “colour modified” so that each of the features within the models was given a unique colour (outlined in chapter 5, table 5.2) whilst leaving any opacity maps that were present intact. Table 6.7 shows which colours were applied to which features.

Colour	Pre-development	During quarrying	Post-development
Red	Buildings	Buildings	Buildings
Green	Vegetation	Vegetation	Vegetation
Blue	River	River	River and lake
Yellow	Not applicable	Not applicable	Fence
Cyan	Not applicable	Quarry workings	Not applicable
Magenta	Pylons	Pylons	Pylons
Black	Sky	Sky	Sky
White	Ground	Ground	Ground

Table 6.7: Application of colour to features within the three models.

Images were then rendered from the four critical viewpoints for the three models with an aspect ratio of 4:3 at a resolution of 800 by 600. Figure 6.61 shows the colour modified rendered image from critical viewpoint one during the quarrying development stage. These twelve images were then analysed by the Bitmap Colour Counter software utility and the results saved as delimited text files.

Using Microsoft Excel, a popular spreadsheet software package, the text files were formatted to produce tables 6.8 to 6.11 and their associated graphs 6.1 to 6.4 which show the percentage view of each model feature for the three models, from each critical viewpoint.

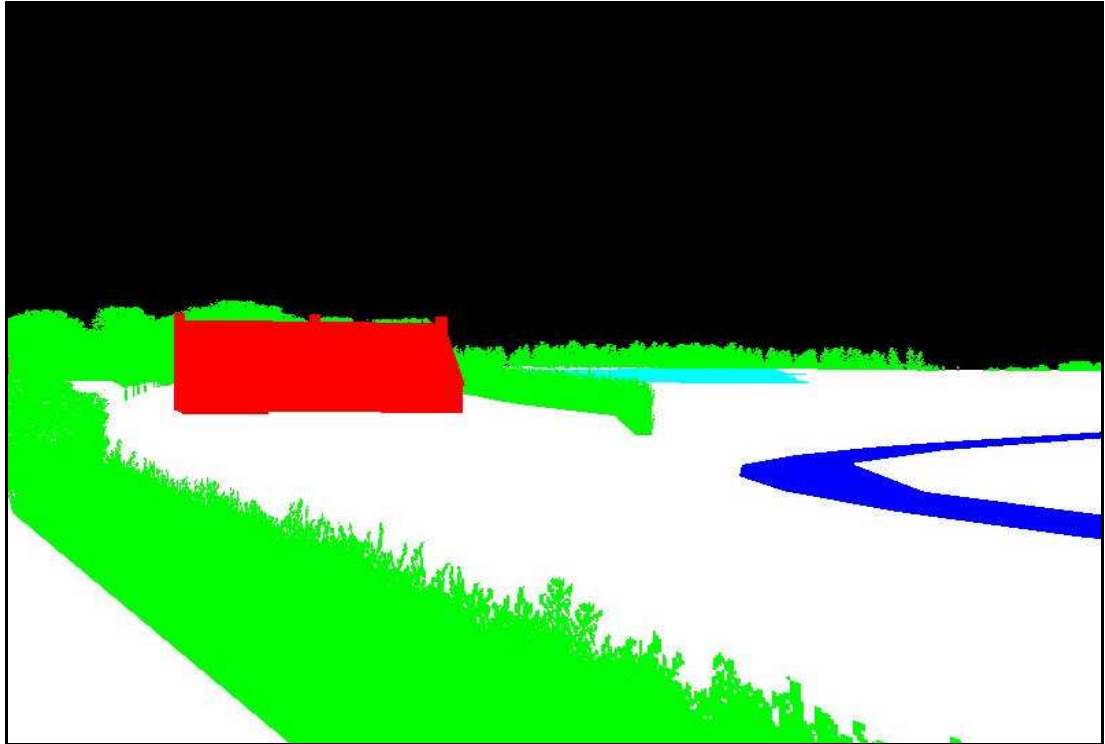


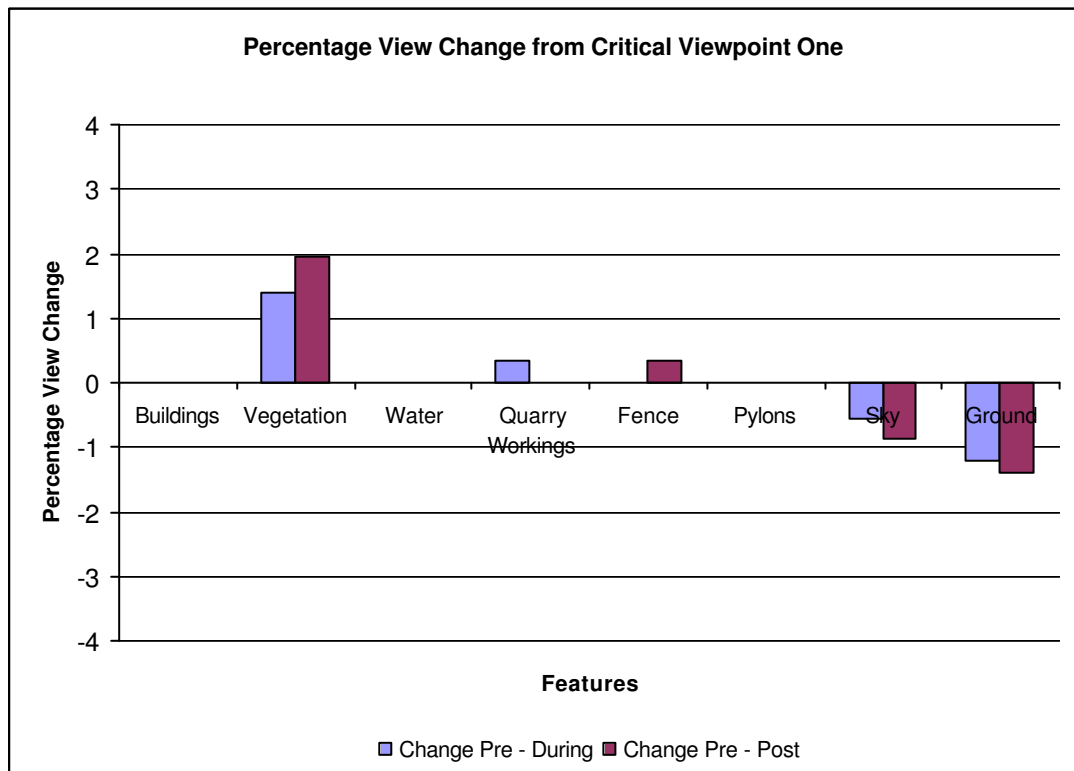
Figure 6.61: Colour modified image of the during quarrying model from critical viewpoint one¹⁸¹.

For critical viewpoint one, there is a 1.4 percent increase in view of vegetation during the quarrying stage when compared with the pre-development model. This percentage will increase to 1.94 when the quarry site has been reclaimed. During the quarrying stage, 0.35 percent of the view from critical viewpoint one will be taken up by quarry workings. For critical viewpoint two, the percentage increase in vegetation is 1.25 percent during quarrying and 1.44 percent post-development. Only 0.01 percent of critical viewpoint two is taken up by quarry workings. A larger change in view can be seen from critical viewpoint three with a 3.36 percentage increase in view of vegetation during quarrying and 3.33 percent post-development. However, the quarry workings will not be visible from this viewpoint. Critical viewpoint four, however, shows the biggest percentage view changes with an increase in vegetation of approximately 19.7 percent for both during quarrying and post-development with corresponds to a loss in ground coverage view of 18.2 percent. 0.73 percent of the view is taken up by quarry workings and there is a slight loss of 2.24 percent in sky during quarrying and a loss of 1.93 percent post-development.

¹⁸¹ Image by the author (June 2001).

	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
Pre-development	3.22	16.90	1.58	0.00	0.00	0.00	45.70	32.59
During Quarrying	3.22	18.30	1.58	0.35	0.00	0.00	45.15	31.40
Post-development	3.22	18.84	1.58	0.00	0.34	0.00	44.82	31.19
Change Pre - During	0.00	1.40	0.00	0.35	0.00	0.00	-0.55	-1.20
Change Pre - Post	0.00	1.94	0.00	0.00	0.34	0.00	-0.88	-1.40

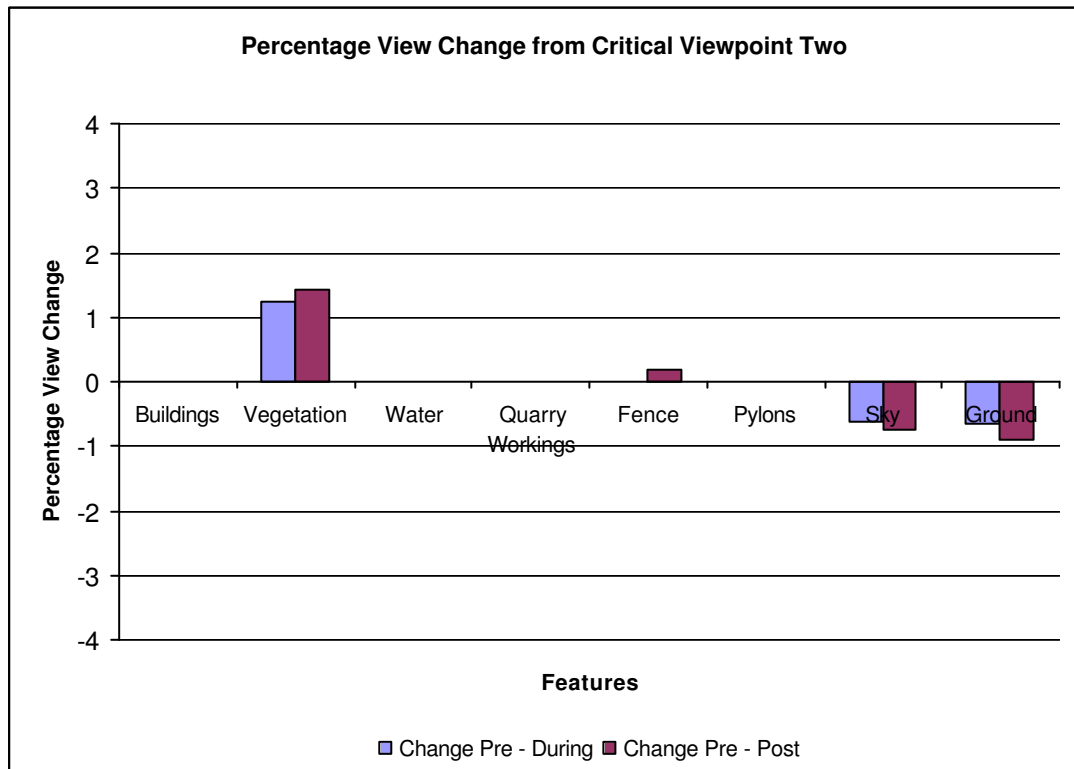
Table 6.8: Percentage view change of various features as viewed from critical viewpoint one.



Graph 6.1: Percentage view change of various features as viewed from critical viewpoint one.

	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
Pre-development	9.46	13.35	0.00	0.00	0.00	0.00	46.25	30.93
During Quarrying	9.45	14.61	0.00	0.01	0.00	0.00	45.63	30.30
Post-development	9.46	14.79	0.01	0.00	0.18	0.00	45.51	30.04
Change Pre - During	-0.01	1.25	0.00	0.01	0.00	0.00	-0.62	-0.64
Change Pre - Post	0.00	1.44	0.01	0.00	0.18	0.00	-0.74	-0.89

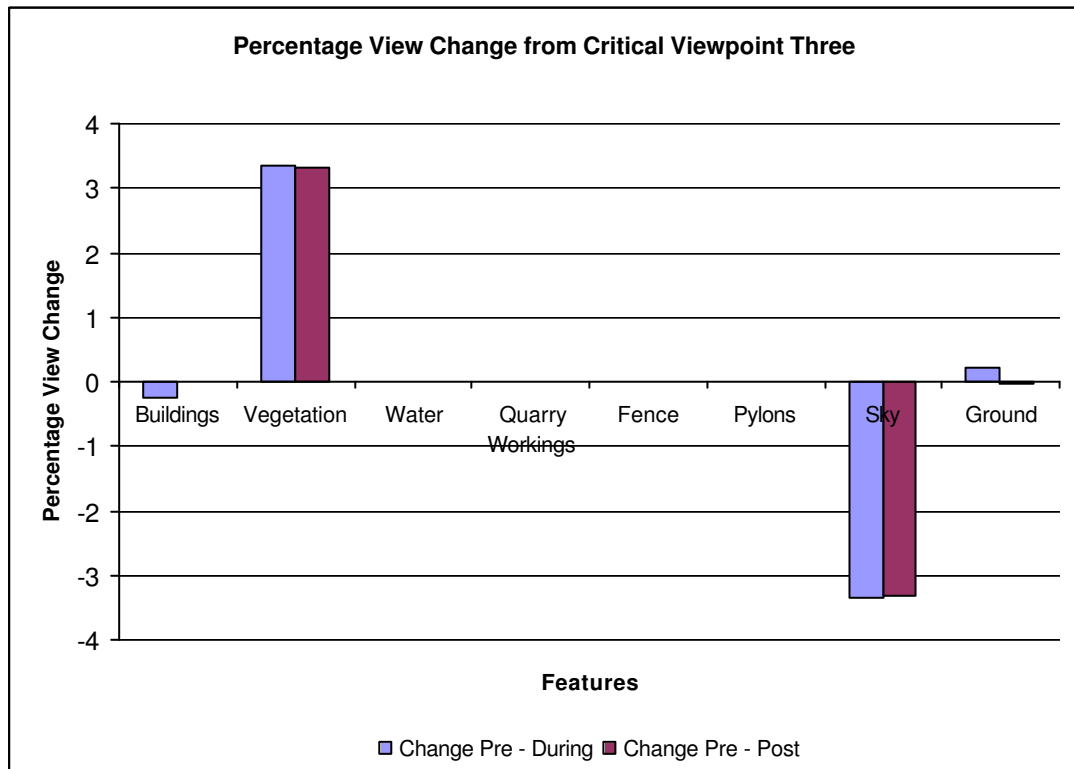
Table 6.9: Percentage view change of various features as viewed from critical viewpoint two.



Graph 6.2: Percentage view change of various features as viewed from critical viewpoint two.

	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
Pre-development	13.23	4.21	0.00	0.00	0.00	0.00	44.99	37.57
During Quarrying	13.00	7.57	0.00	0.00	0.00	0.00	41.65	37.78
Post-development	13.23	7.54	0.00	0.00	0.00	0.00	41.68	37.54
Change Pre - During	-0.24	3.36	0.00	0.00	0.00	0.00	-3.34	0.21
Change Pre - Post	0.00	3.33	0.00	0.00	0.00	0.00	-3.31	-0.02

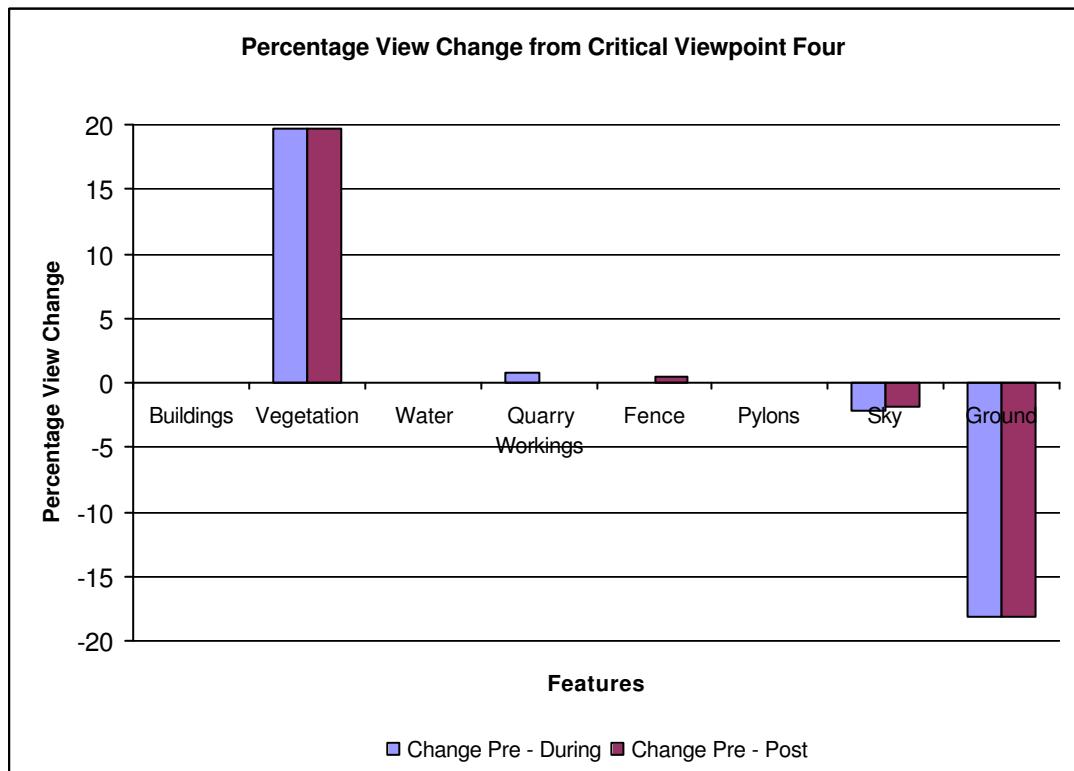
Table 6.10: Percentage view change of various features as viewed from critical viewpoint three.



Graph 6.3: Percentage view change of various features as viewed from critical viewpoint three.

	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
Pre-development	0.00	8.34	0.00	0.00	0.00	0.00	45.55	46.11
During Quarrying	0.00	28.07	0.00	0.73	0.00	0.00	43.31	27.90
Post-development	0.00	28.04	0.00	0.00	0.41	0.00	43.62	27.94
Change Pre - During	0.00	19.73	0.00	0.73	0.00	0.00	-2.24	-18.21
Change Pre - Post	0.00	19.70	0.00	0.00	0.41	0.00	-1.93	-18.17

Table 6.11: Percentage view change of various features as viewed from critical viewpoint four.



Graph 6.4: Percentage view change of various features as viewed from critical viewpoint four.

The percentage view change of features within the three Tiln South models has also been investigated for a series of points along the road which passes through Tiln South (figure 6.62). A camera was attached to a spline object which was modelled to follow part of the road at a height of 1.7 metres in order to simulate the view a person would have if walking down the road. Using the three colour modified models, animations were rendered over 250 frames and saved as uncompressed “avi” files. The three animations were then passed through the Bitmap Colour Counter utility to obtain delimited text files of the percentage view of each uniquely coloured feature within the models. The animation can be found on the CD-ROM in appendix 9. Tables 6.12 and 6.13 and their respective graphs 6.5 and 6.6, summarise the percentage view change of various features of the pre-development model with the during quarrying and post-development models for every twenty fifth frame.

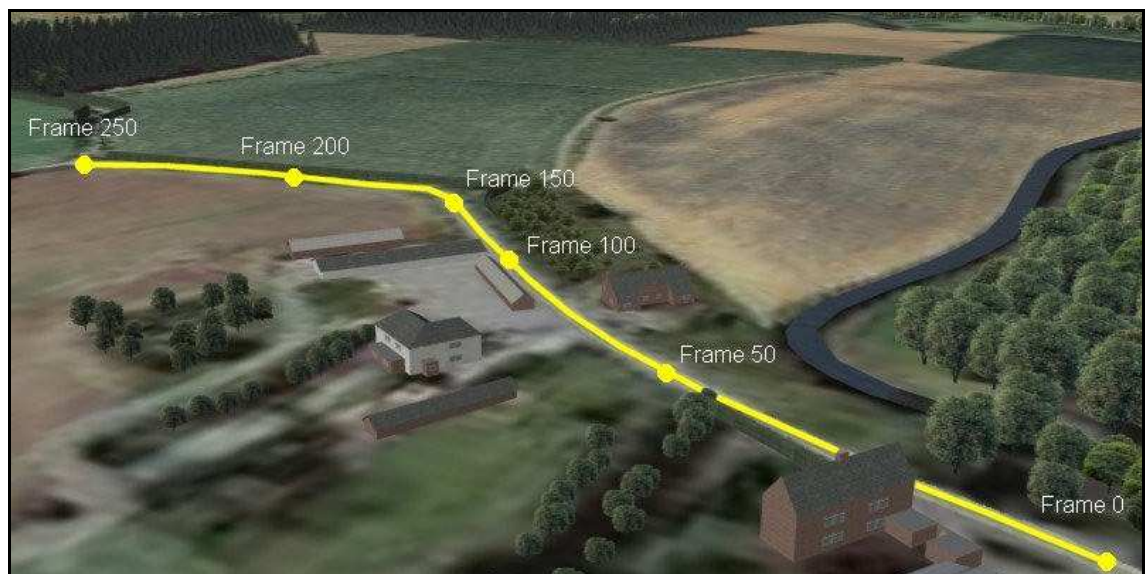


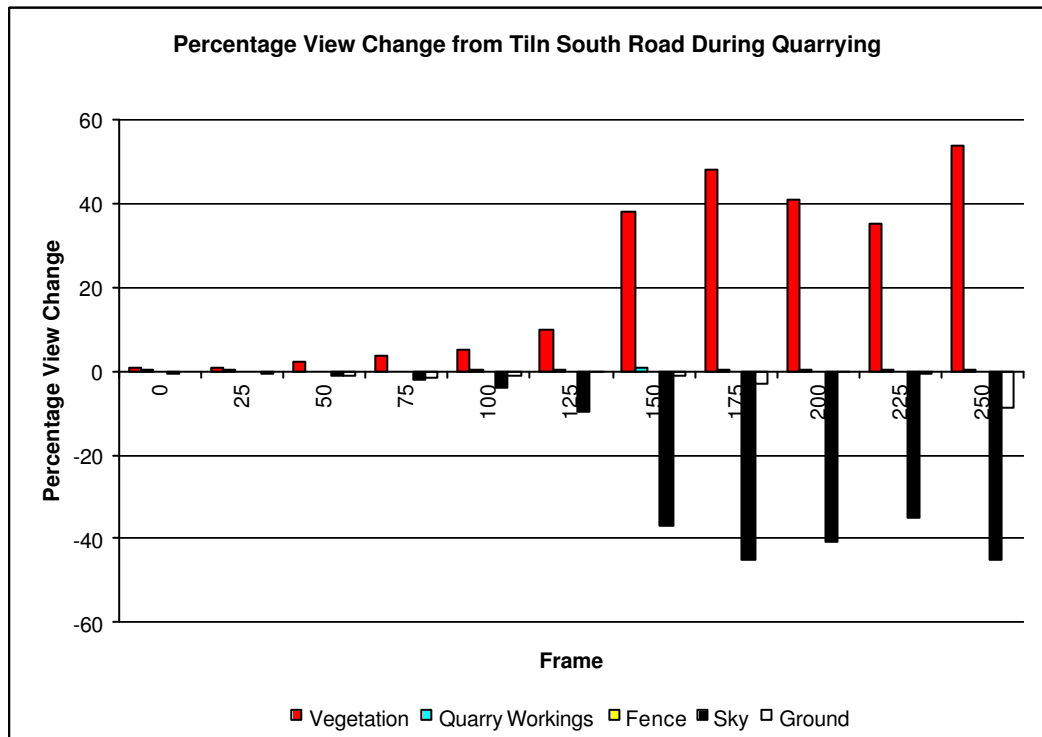
Figure 6.62: Location of road along which animation was performed¹⁸².

The results show that the quarry workings do not constitute a high percentage of view from the road through Tiln South. The highest percentage view of quarry workings takes place at frames 145 and 220 at a percentage view of 0.99 percent. Due to the new vegetative screening proposals, there is a high percentage increase in view of vegetation ranging from 35 to 55 percent which occurs from frames 150 to 250 for both during quarrying and post-development.

¹⁸² Images from a 3D model created by the author (June 2001).

Frame	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
0	0.00	0.63	0.00	0.03	0.00	0.00	-0.55	-0.11
25	0.00	0.62	0.00	0.17	0.00	0.00	-0.11	-0.69
50	0.00	2.38	0.00	0.00	0.00	0.00	-1.11	-1.27
75	0.00	3.69	0.00	0.00	0.00	0.00	-2.23	-1.46
100	0.00	4.87	0.00	0.14	0.00	0.00	-4.01	-1.00
125	0.00	9.88	0.00	0.12	0.00	0.00	-9.77	-0.23
150	0.00	37.68	0.00	0.73	0.00	0.00	-37.14	-1.27
175	0.00	48.02	0.00	0.02	0.00	0.00	-44.94	-3.10
200	0.00	40.96	0.00	0.13	0.00	0.00	-40.86	-0.23
225	0.00	35.34	0.00	0.35	0.00	0.00	-35.18	-0.52
250	0.00	53.93	0.00	0.03	0.00	0.00	-44.95	-9.02

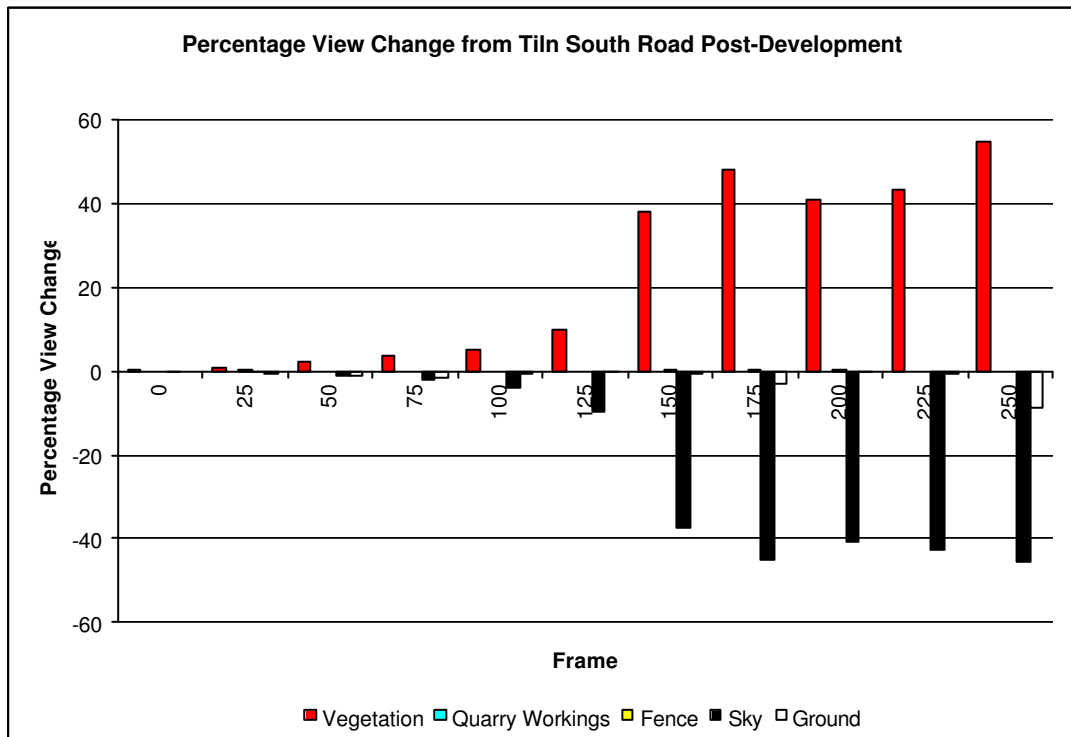
Table 6.12: Percentage view change from the road through Tiln South during quarrying.



Graph 6.5: Percentage view change from the road through Tiln South during quarrying.

Frame	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
0	0.00	0.43	0.00	0.00	0.00	0.00	-0.32	-0.12
25	0.00	0.96	0.00	0.00	0.27	0.00	-0.36	-0.87
50	0.00	2.39	0.00	0.00	0.00	0.00	-1.12	-1.27
75	0.00	3.69	0.00	0.00	0.00	0.00	-2.23	-1.46
100	0.00	4.90	0.00	0.00	0.00	0.00	-4.01	-0.89
125	0.00	9.87	0.00	0.00	0.00	0.00	-9.73	-0.14
150	0.00	37.78	0.00	0.00	0.11	0.00	-37.22	-0.68
175	0.00	48.00	0.00	0.00	0.01	0.00	-44.92	-3.09
200	0.00	41.00	0.00	0.00	0.00	0.00	-40.81	-0.19
225	0.00	43.29	0.00	0.00	0.00	0.00	-42.76	-0.53
250	0.00	54.51	0.00	0.00	0.00	0.00	-45.52	-8.99

Table 6.13: Percentage view change from the road through Tiln South post-development.



Graph 6.6: Percentage view change from the road through Tiln South post-development.

6.4.7 Seasonal Variation

The effect of the proposed vegetative screening on the visual impact of the proposed quarry has been assessed using visualisation, FVI and percentage view change techniques. However, these techniques have been performed whilst assuming a summer climate when the vegetation is in full leaf. During the autumn and winter seasons, however, some of the vegetative screening will become bare, and hence the screening ability of the vegetation may become reduced.

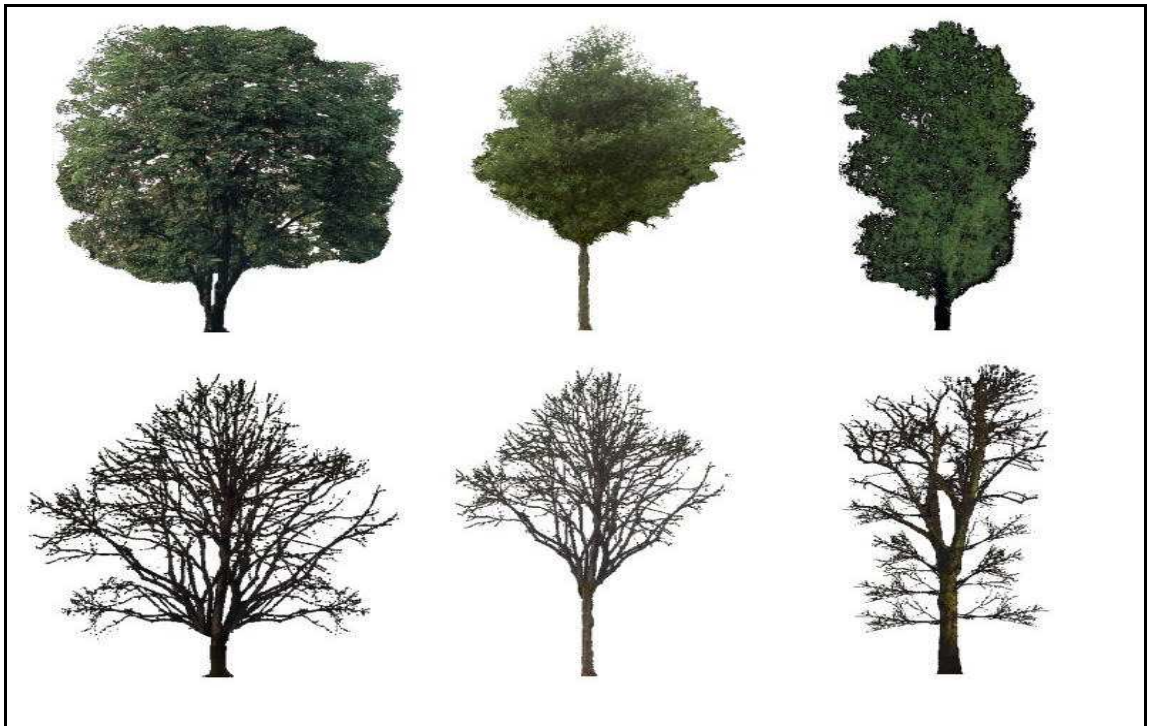


Figure 6.63: Selection of summer and winter tree textures¹⁸³.

To assess the visual impact of the proposed quarry during the winter season, the three 3D CG models were modified in order to represent winter models. This was achieved by changing the texture maps of deciduous vegetation models to appropriate winter versions. Figure 6.63 shows a selection of the deciduous texture maps which have been changed with winter texture maps.

Figure 6.64 shows a rendered image of the view from critical viewpoint two during quarrying in

¹⁸³ Images by the author (June 2001).

the winter. The colour modified models (described in section 6.46) were also modified to represent the winter season and figure 6.65 shows the rendered image from critical viewpoint two from the colour modified winter during quarrying model. All of the winter critical viewpoint rendered images can be found in appendix 8.



Figure 6.64: Rendered view from critical viewpoint two during the quarrying stage¹⁸⁴.

The percentage view change was assessed for each critical viewpoint for each of the three quarry development stages and table 6.14 summarises the results. Graphs 6.7 to 6.10 display this information graphically.

The results show that the percentage view of quarry workings for all four critical viewpoints is very similar in summer as it is in winter. The percentage view and percentage view change of other features are also relatively unchanged from summer to winter. Therefore it can be deduced that the effect of seasonal variation on the visual impact of the proposed quarry is marginal.

¹⁸⁴ Image from a 3D model created by the author (June 2001).

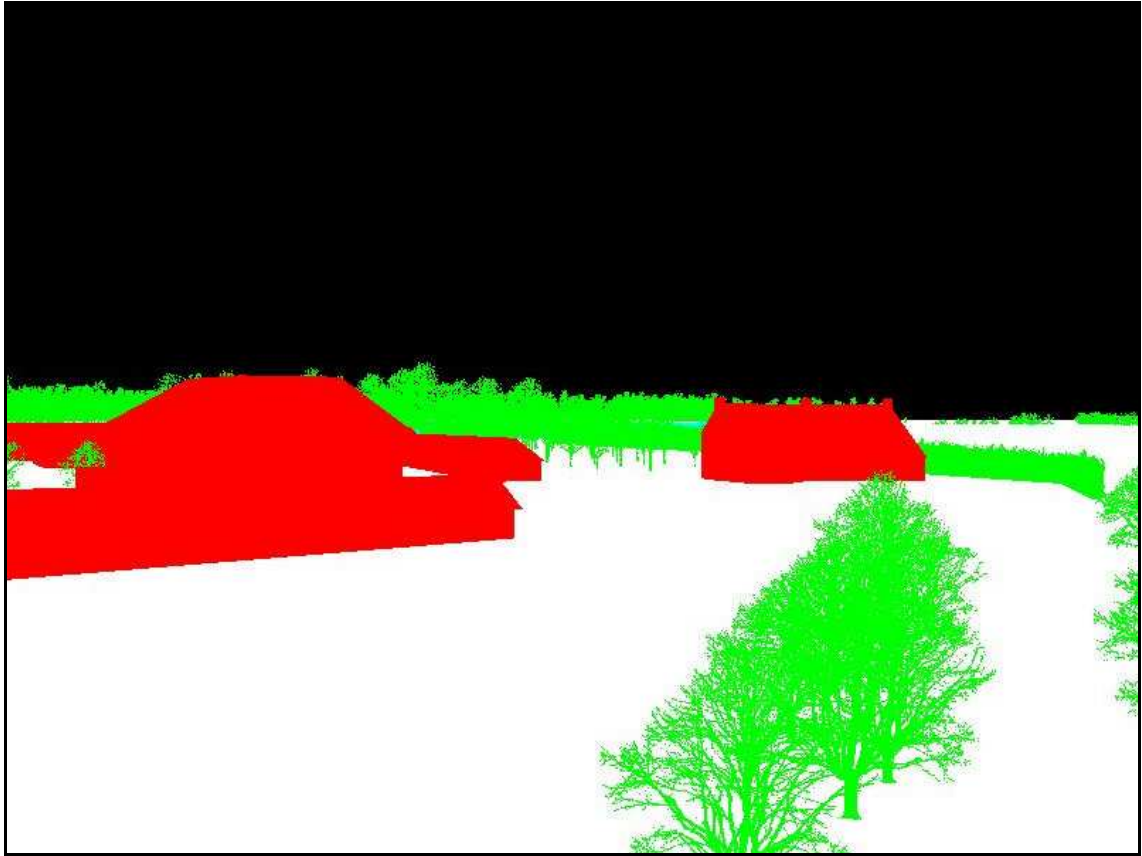
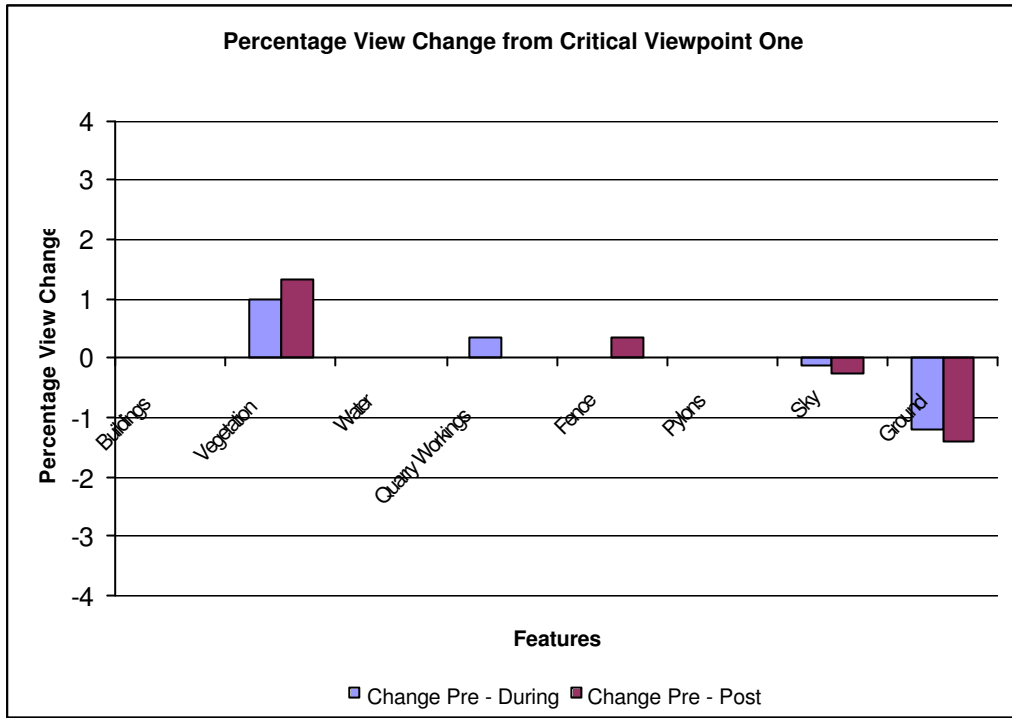


Figure 6.65: Critical viewpoint two during the quarrying stage of the winter colour modified model¹⁸⁵.

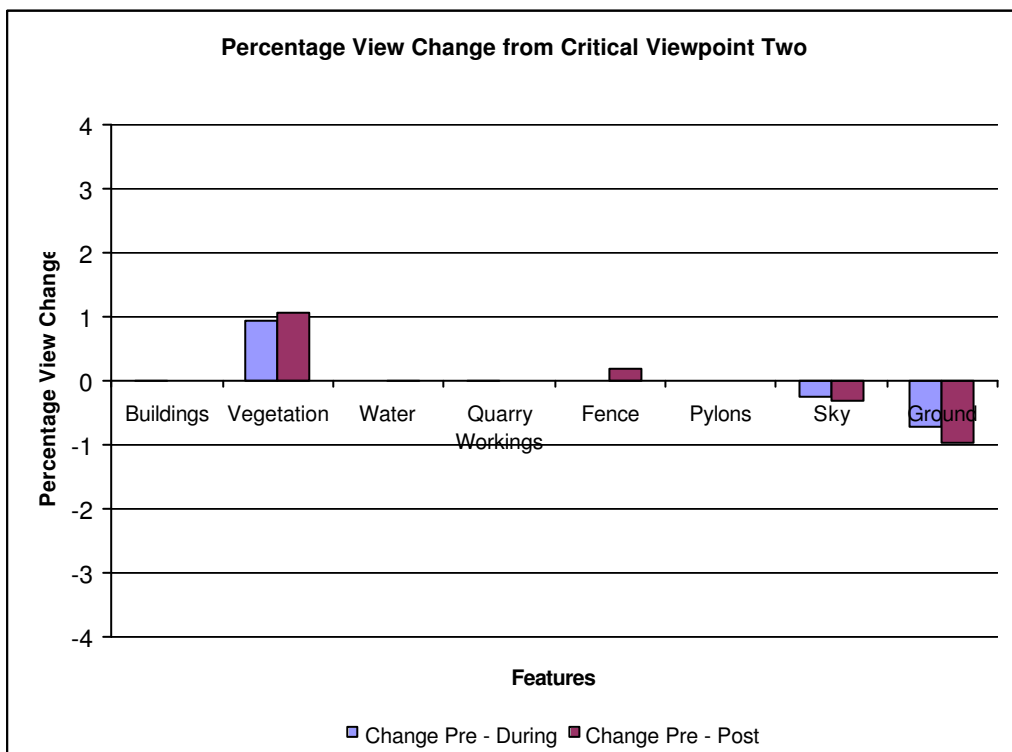
	Critical Viewpoint	Buildings	Vegetation	Water	Quarry Workings	Fence	Pylons	Sky	Ground
Change Pre - During	1	0.00	0.98	0.00	0.35	0.00	0.00	-0.13	-1.20
	2	-0.01	0.95	0.00	0.02	0.00	0.00	-0.24	-0.72
	3	-0.24	2.25	0.00	0.00	0.00	0.00	-2.08	0.06
	4	0.00	18.63	0.00	0.82	0.00	0.00	-1.18	-18.27
Change Pre - Post	1	0.00	1.31	0.00	0.00	0.35	0.00	-0.26	-1.40
	2	0.00	1.07	0.01	0.00	0.19	0.00	-0.30	-0.98
	3	0.00	2.39	0.00	0.00	0.00	0.00	-2.22	-0.17
	4	0.00	18.72	0.00	0.00	0.42	0.00	-0.97	-18.17

Table 6.14: Percentage view change of various features as viewed in winter.

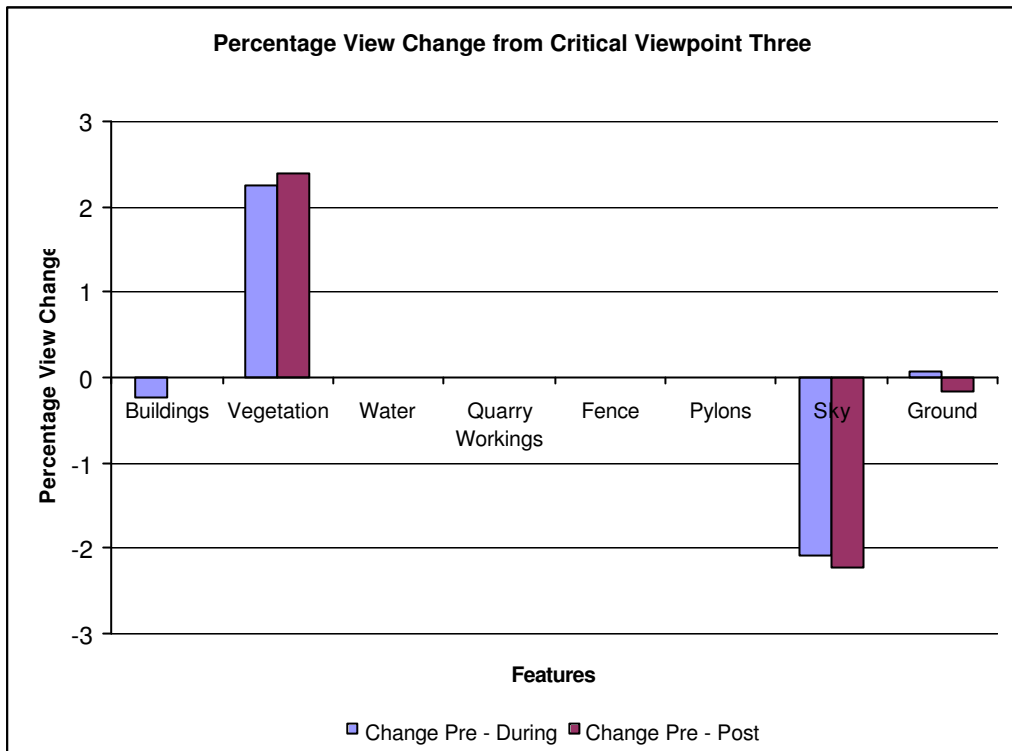
¹⁸⁵ Image from a 3D model created by the author (June 2001).



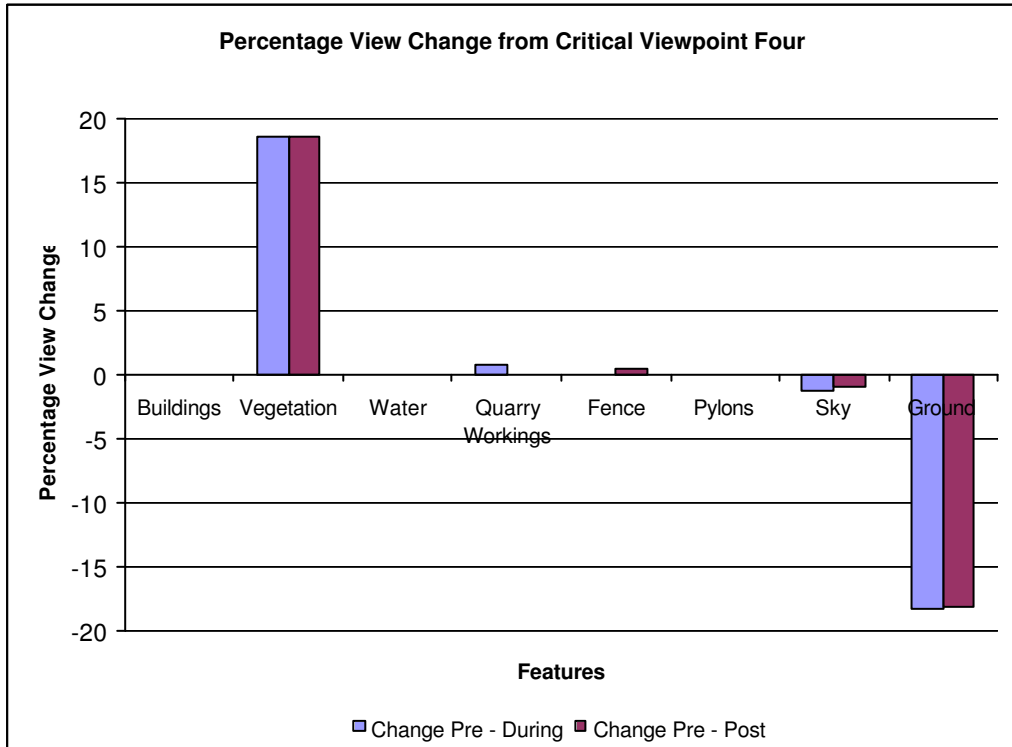
Graph 6.7: Percentage view change of various features as viewed in winter from critical viewpoint one.



Graph 6.8: Percentage view change of various features as viewed in winter from critical viewpoint two.



Graph 6.9: Percentage view change of various features as viewed in winter from critical viewpoint three.



Graph 6.10: Percentage view change of various features as viewed in winter from critical viewpoint four.

6.4.8 Integrated Visual Impact Assessment Using Virtual Reality

Various novel CG techniques have been used to assess the visual impact of the proposed quarry near Tiln South. However, these techniques have all been methods whereby the visual impact has been assessed from fixed viewpoints or set paths. Therefore, a VR simulation of the Tiln South environment has been created, using Macromedia Director Shockwave Studio 8.5, which does not restrict the user to fixed viewpoints or paths.

Chapter 5 briefly described the development of the “Real-Time PVA Simulation” with Dene Quarry as an example. The Tiln South case study uses a similar simulation but with a few extra features and different 3D models, animations and images.

The pre-development, during quarrying and post-development models were combined into one large model. The tree and scattered shrub models were changed from single plane objects to double plane objects with the planes intersecting one another at right angles (see figure 6.27). This step was necessary since the trees and shrub models could not be efficiently rotated, once inside the simulation, to face the virtual camera at all times.

The entire model was then exported as a “W3D” file, imported into Macromedia Director and then loaded into the VR simulation which was created earlier (described in chapter 5). The above steps were also repeated for the colour modified models.

Figure 6.66 shows a screenshot of the Tiln South Real-Time PVA Simulation interface. The before, during and after buttons are used to hide or show the pre-development, during quarrying and post-development features of the model. Pressing the altered 3D view button will hide the entire regular model, and show the colour modified model (figure 6.67). It is this model that is used to calculate the percentage view of various features of the environment using the real-time colour counting function (also referred to as the real-time percentage view analyser and

described in more detail in chapter 5). Results from the real-time percentage view analyser can be saved as a delimited text file by entering a file name and pressing the save button. The text file can then be subsequently opened as a table in a spreadsheet software package.

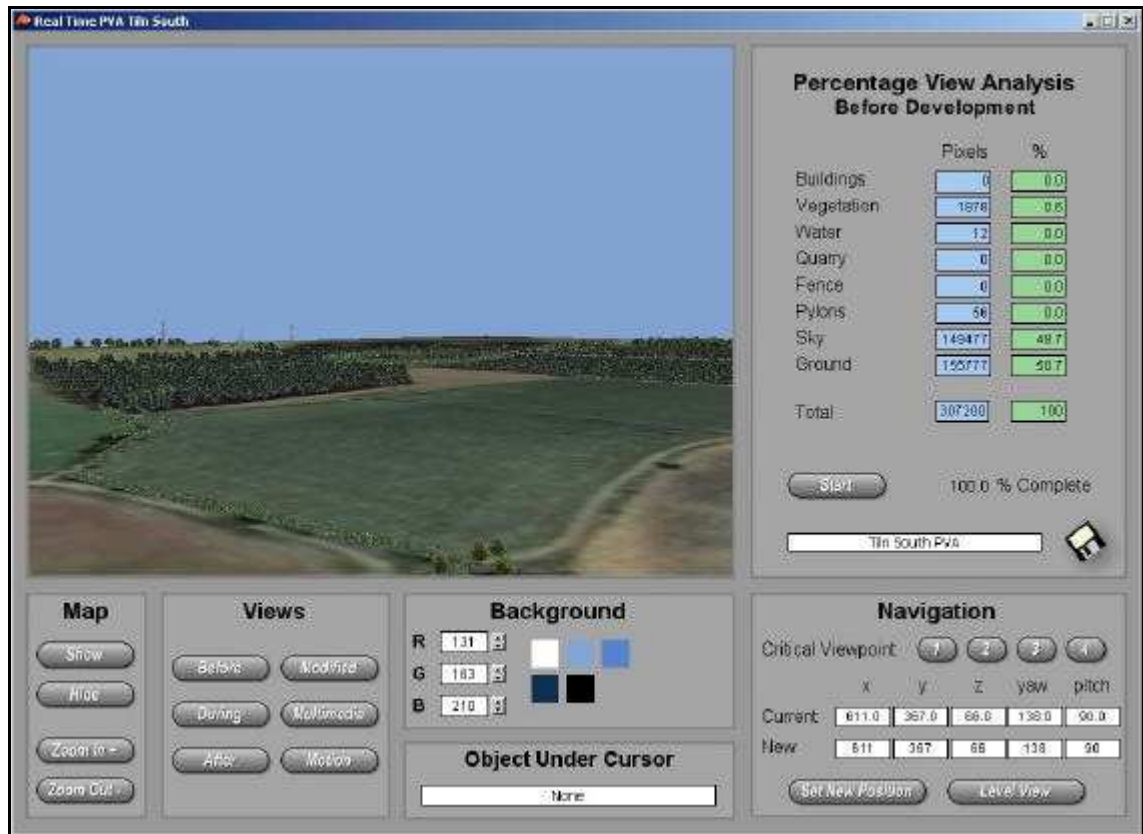


Figure 6.66: Tilt South Real-Time PVA Simulation interface¹⁸⁶.

The user may also view static images and animations which were produced earlier, including: the rendered images from the four critical viewpoints, rendered images from perspective aerial views, the three cumulative FVIs, OS maps indicating the position of the quarry site, development plans, and the three fly around animations. Figure 6.68 shows the cumulative FVI for the quarrying stage of the development within the VR simulation.

¹⁸⁶ 3D model and VR simulation created by the author (December 2002).

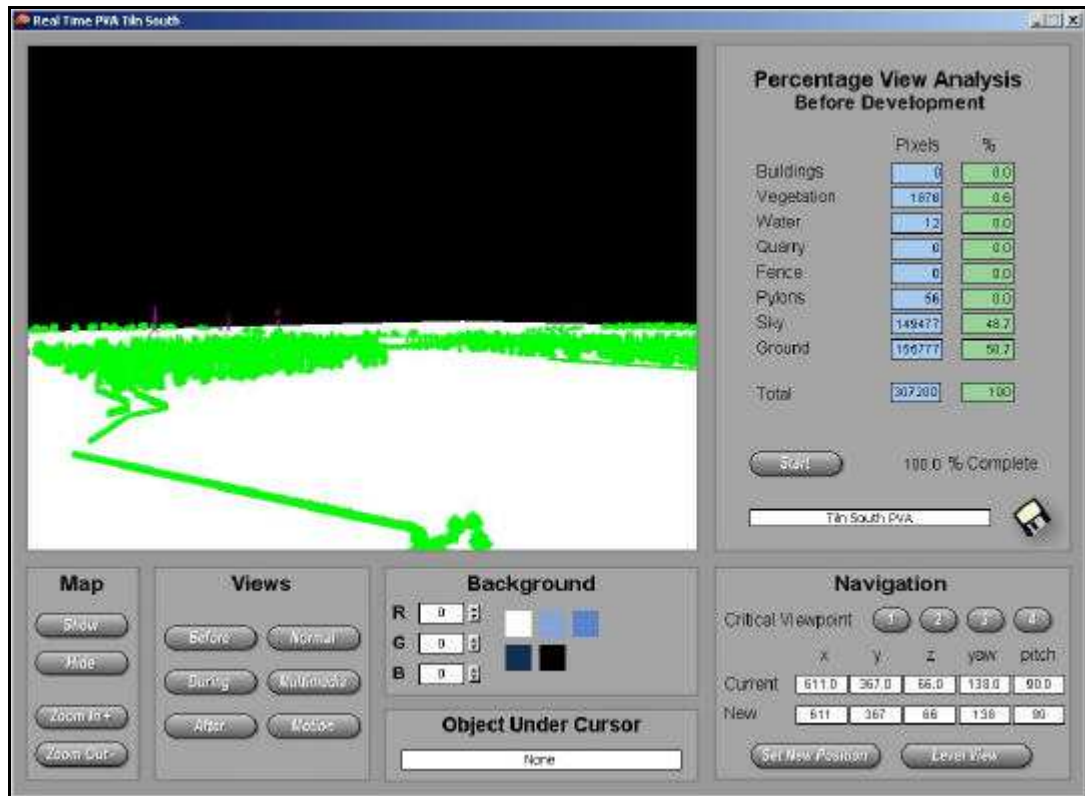


Figure 6.67: Tilt South Real-Time PVA Simulation interface displaying the colour modified model¹⁸⁷.

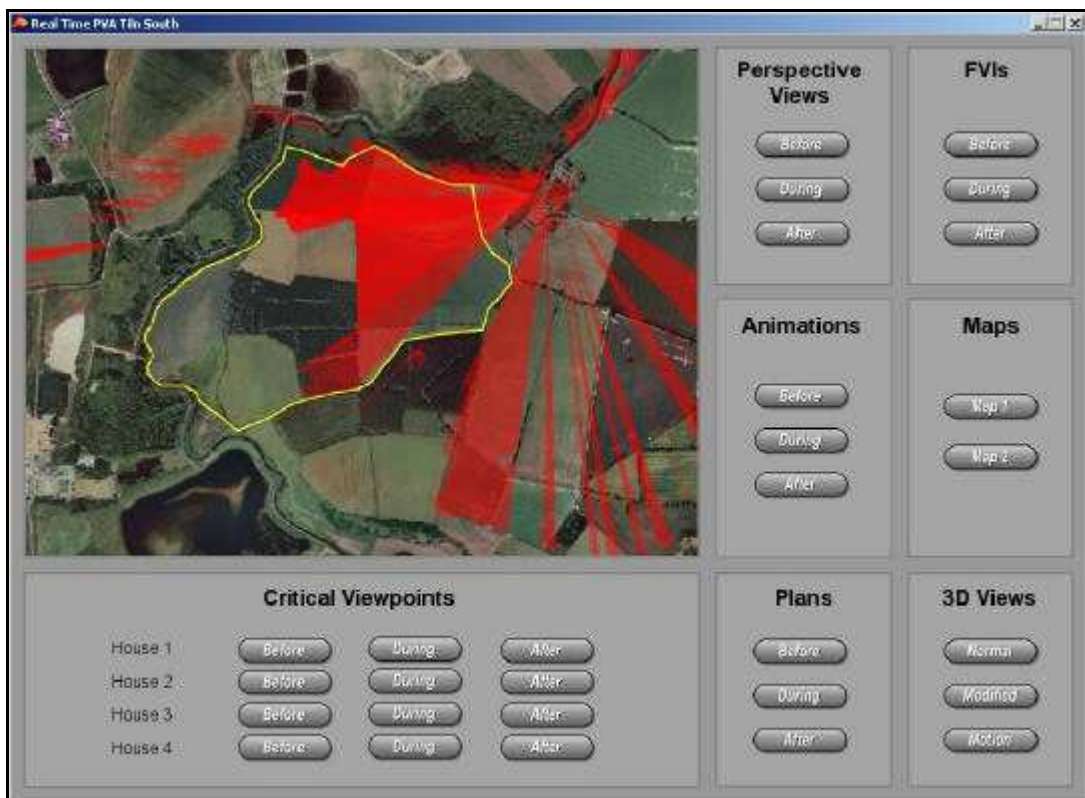


Figure 6.68: Tilt South Real-Time PVA Simulation interface showing an FVI¹⁸⁸.

¹⁸⁷ 3D model and VR simulation created by the author (December 2002).

¹⁸⁸ Image and VR simulation created by the author (December 2002).

An extra feature was added to the Tiln South VR simulation that enabled the user to instantaneously observe percentage view change figures from a series of viewpoints along the road going through the hamlet of Tiln South looking towards the proposed quarry site.

By importing the camera that was animated along the road through Tiln South (previously modelled and described in section 6.46) into the VR simulation, the user is able to navigate along the length of the road, whilst looking towards the proposed quarry site, using a slider button (figure 6.69). The percentage view results, which were previously determined for viewpoints along the road, were also imported into the simulation. Using this data, the percentage view results for the current position along the road are displayed as a table and a graph. A map is also provided to indicate the current position of the view within the VR environment.

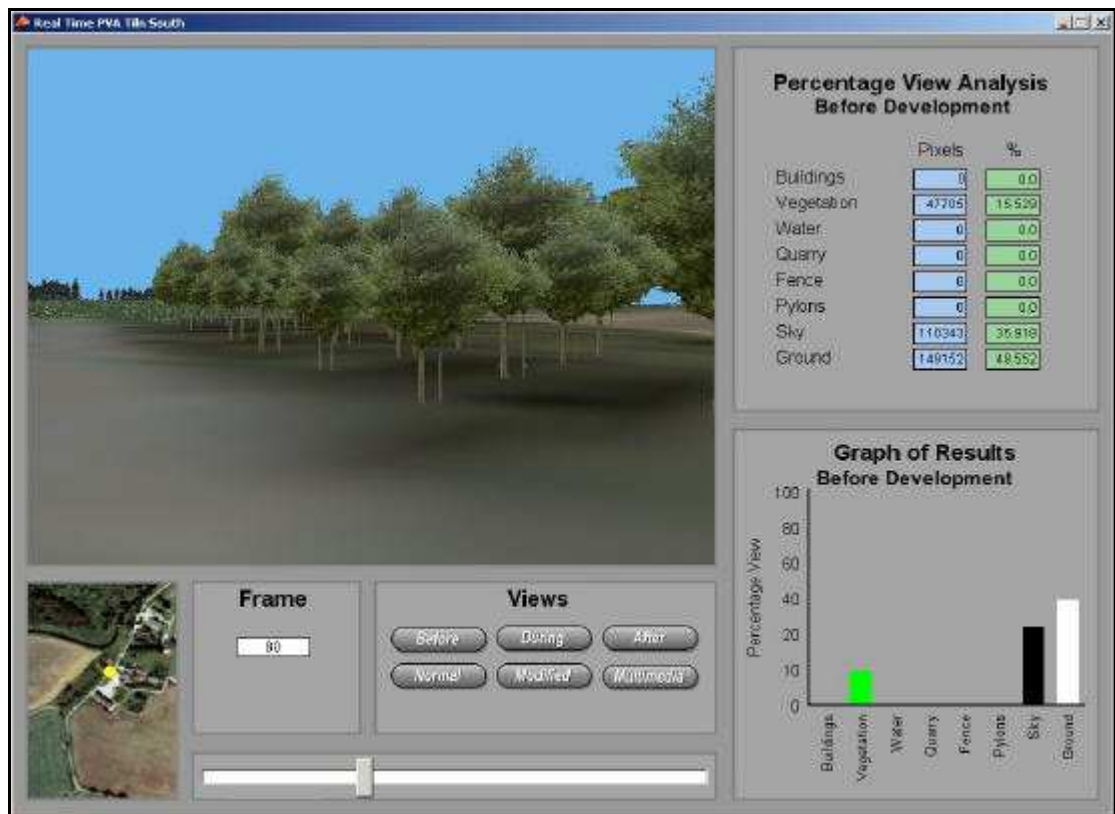


Figure 6.69: Tiln South Real-Time PVA Simulation “motion” interface¹⁸⁹.

¹⁸⁹ Image and VR simulation created by the author (December 2002).

Using the critical viewpoint navigation buttons, it was possible to compare the similarity of the VR model with the 3D Studio MAX model. For each critical viewpoint for each development stage, a real-time percentage view analysis was performed and the results compared with the Bitmap Colour Counter results that were previously performed. Table 6.15 shows the differences between the two percentage view assessment techniques. The 3D views from the VR simulation were also visually compared with the previously rendered images to check the 3D models were consistent with each other. Small discrepancies were expected due to the change to the tree and shrub models and the results confirm this.

Critical Viewpoint	Feature	Difference		
		Pre-development	During Quarrying	Post-development
One	Buildings	0.18	0.18	0.18
	Vegetation	-0.60	-0.80	-0.84
	Water	-0.08	0.02	-0.08
	Quarry	0.00	0.05	0.00
	Fence	0.00	0.00	0.06
	Pylons	0.00	0.00	0.00
	Sky	0.40	0.55	0.48
	Ground	0.11	0.00	0.11
Two	Buildings	0.44	0.45	0.44
	Vegetation	-0.45	-0.41	-0.39
	Water	0.00	0.00	-0.01
	Quarry	0.00	-0.01	0.00
	Fence	0.00	0.00	0.02
	Pylons	0.00	0.00	0.00
	Sky	0.25	0.17	0.19
	Ground	-0.23	-0.30	-0.24
Three	Buildings	0.37	0.40	0.37
	Vegetation	-0.01	-0.17	-0.24
	Water	0.00	0.00	0.00
	Quarry	0.00	0.00	0.00
	Fence	0.00	0.00	0.00
	Pylons	0.00	0.00	0.00
	Sky	0.41	0.55	0.62
	Ground	-0.77	-0.78	-0.74
Four	Buildings	0.00	0.00	0.00
	Vegetation	-1.44	-1.87	-1.74
	Water	0.00	0.00	0.00
	Quarry	0.00	0.27	0.00
	Fence	0.00	0.00	-0.01
	Pylons	0.00	0.00	0.00
	Sky	0.45	0.89	0.68
	Ground	0.99	0.70	0.96

Table 6.15: Difference in percentage view results between VR and 3D Studio MAX models.

The average discrepancies for the pre, during and post development, using absolute values, are 0.22, 0.27 and 0.26 percent respectively. The largest discrepancy is a percentage difference of 1.87 which occurred for the vegetation of critical viewpoint four. This inaccuracy, however, is a direct result of the difference in the way the trees and shrubs were modelled and it can be seen that most of the discrepancies are due to the vegetation models. Overall, the differences in percentage views are well within acceptable margins of error and this shows that the Tiln South Real-Time PVA Simulation is almost as accurate as the 3D Studio MAX model for determining the visual impact of the proposed quarry.

6.4.9 Analysis

An extension to Bellmoor Quarry, located near the hamlet of Tiln South, was proposed by Tarmac Quarry Limited for the extraction of sand and gravel. On completion of quarrying, it was proposed to restore the land for agriculture, forestry and water.

Originally undertaken in 1993 by AIMS Research, at the University of Nottingham, this environment has been remodelled using current modelling techniques and used as a case study to demonstrate the novel VIA techniques which have been developed in this thesis. The development of the quarry was split into three separate stages for modelling and assessment which were: pre-development, during quarrying and post-development. In a short time span, the three models were created using 3D Studio MAX version 3.1 and data which was originally supplied to AIMS Research by Tarmac Quarry Limited.

For each of the four houses situated in Tiln South, a critical viewpoint was established. For each critical viewpoint during each development stage, visualisations, FVIs and percentage view changes were produced using the novel techniques described in chapter 5.

Accurate single reflective FVIs were produced for each critical viewpoint for each development

stage and graphically illustrated which critical viewpoints would be affected by each development stage. This information could be used to highlight views that may need more screening from the quarry. The single reflective FVIs were also combined to produce cumulative reflective FVIs which showed which areas of land were the most visible from the four critical viewpoints. The deeper the shade of red, the more critical viewpoints can see that area. The FVIs showed that a small proportion of the quarry workings could be seen from the critical viewpoints. In order to improve the results, FVIs could have been produced from every window within each house and also for other visually sensitive receptors such as gardens and footpaths. It should be noted, however, that FVIs produced using this technique can only be as accurate as the 3D model employed.

The Bitmap Colour Counter utility was used on the colour modified rendered images from the critical viewpoints from each development stage. The results showed a clear increase in vegetation and this was due to the proposed screening. The percentage of view taken up by the quarry was limited to 0.35, 0.01, 0 and 0.73 for critical viewpoints one to four respectively. This confirms the effectiveness of the proposed vegetative screening. A percentage view change assessment was also performed for a series of points along the road that passes through Tilm South. The results obtained from this analysis showed that the highest percentage view of the quarry workings was only 0.99 percent and occurred at frame 145 which corresponds to the location along the road where there is a clear gap in screening between some apple trees and a hedge.

By changing the vegetation textures in the three models to winter textures, the effect of seasonal variation was determined. Using these new winter models, the percentage view change from each critical viewpoint was re-calculated. The results showed a small average percentage increase in view of the quarry by 0.03 during winter as opposed to summer. There were equally small differences between the percentage view changes of other features within the models during summer and winter. It was inferred that the effect of seasonal variation on the visual

impact of the proposed quarry is marginal and therefore the screening effect of the proposed and existing vegetation is virtually as effective in winter as it is in summer.

The Real-Time PVA Simulation which was developed and described in chapter 5, was used as a basis for producing a VR simulation which integrated VR techniques with other forms of VIA such as static and animated visualisations, FVIs and percentage view change analysis. The 3D CG models which were initially used to produce the results described above, were exported into the VR simulation which was developed using Macromedia Director Shockwave Studio. The user is able to freely navigate around the Tilt South environment switching between the three development stages at will. This unrestricted movement around the environment prevents bias due to fixed viewpoints and helps the user visualise the environment more clearly. FVIs and visualisations which were previously produced can be viewed within the VR simulation and there is also a function for calculating the percentage of view of various features in real-time and viewing pre-determined percentage view figures for a pre-defined animated path.

One benefit of such a VR simulation is that it integrates many forms of VIA techniques and therefore can assess the visual impact on the environment spatially, qualitatively and quantitatively. Unlike many VR simulations which require VR software to be purchased in order to run the simulations, the Real-Time PVA Simulation is free to distribute. The simulation is also small in terms of digital storage (approximately 32 megabytes) and therefore it can be easily distributed either over the internet or on CD-ROM.

6.5 Summary

Three case studies have been presented that demonstrate some of the new and enhanced techniques that have been developed that can be used to assess the visual impact of proposed developments and to solve some of the problems associated with computerised VIA techniques that have been illustrated in chapter 4.

The Stoke Approach corridor study involved the visualisation of a number of features which were proposed to enhance the overall appearance of the area. Using CG 3D modelling techniques a model of the Hartshill area was produced that was then used to create pre-development and post-development animations from a single key viewpoint. Quantitative analysis, in the form of a percentage view change assessment, was then performed of the view from the critical viewpoint using the Bitmap Colour Counter utility (described in detail in chapter 5).

The Birmingham university hospital case study was concerned with the development of a new university hospital and the relocation of an existing psychiatric hospital. Critical viewpoints were identified by Babbie Group for each of these developments, and for each of these viewpoints various VIA techniques were used, in conjunction with a 3D CG model of the environment, to produce:

- ?? rendered images or photomontages,
- ?? animations,
- ?? and percentage view change analyses.

A VR simulation of the proposed university hospital development was also produced using Safe-VR. The simulation enables a user to visualise the proposed hospital site pre and post-development as well as viewing photographs, photomontages, and FVIs. Pre-determined percentage view change results from a local tower block can also be displayed graphically on the side of the tower block.

The Tiln South case study involved the visual impact analysis of a proposed quarry near the hamlet of Tiln South. The various forms of VIA which were used include:

- ?? rendered images,
- ?? animations,
- ?? FVIs,
- ?? percentage view analysis.

The effect of seasonal variation was investigated by comparing percentage view results from summer and winter models. The summer model used fully leafed vegetation texture maps, whilst the winter model used bare leafed vegetation texture maps.

A VR simulation of the Tiln South environment was also created using Macromedia Director. The simulation enables a user to freely navigate around the environment, switching between the pre, during and post-development stages. Real-time percentage view analysis is possible using a similar methodology as used by the Bitmap Colour Counter utility, and pre-determined percentage view figures are also available in a table of graph format for a fixed path along the road through the hamlet of Tiln South. The VR simulation also integrates rendered images, animations and FVIs which were previously produced, as well as plans of the proposed quarry development and maps of the environment.

7 Conclusions and Recommendations

7.1 Introduction

Whilst a large proportion of environmental issues can be assessed quantitatively, using guidelines or legislative standards, visual impact is mainly assessed qualitatively, since it is concerned with the human appreciation of the landscape (LITIEMA, 2002 and Wherrett, 2002). The lack of quantitative techniques and extensive use of qualitative techniques leads to a high degree of subjectivity within the field of VIA and therefore it is possible to conclude that there is a need for new techniques to produce a more objective VIA approach.

The aims and objectives of the research detailed in this thesis were to improve upon and develop new techniques, using CG and VR technology, that could be used for the assessment of potential visual impacts arising from proposed developments. In particular, the research aimed to:

- ?? improve the way FVIs were developed,
- ?? develop a technique to quantitatively assess the amount of view taken up by a proposed development,
- ?? develop a VR simulation which incorporated spatial, qualitative and quantitative VIA techniques,
- ?? allow the effects of Earth curvature and atmospheric refraction to be incorporated into the new and improved techniques,
- ?? investigate the effects of seasonal variation and growth of vegetation on visual impact.

The research has met all of the aims and objectives listed above by developing a number of novel techniques. A new technique to produce FVIs has been developed using standard 3D CG modelling techniques. A quantitative method to calculate percentage view change has been developed that allows the accurate determination of the variation in any view, caused by an existing or proposed development. A novel VR simulation technique has also been developed that attempts to reduce the subjectivity associated with simulations, by integrating quantitative

and spatial techniques. A software utility has also been developed that allows the effects of Earth curvature and atmospheric refraction to be incorporated into the new techniques, and a methodology for assessing the change in visual impact of a development due to seasonal variation and growth of vegetation has also been described.

The following sections of this chapter provide a brief overview of the work shown in this thesis, followed by a number of conclusions and recommendations based on the research, regarding the use of CG and VR for VIA.

7.2 Overview of Thesis

A brief history of CG and VR was described in chapter 2, along with the technical background and current applications of these technologies. It was shown that the price of CG and VR software varies to a great extent and the price of hardware is constantly decreasing whilst its capability increases, providing both novice and professional users with a platform to develop images, animations and simulations for a variety of tasks.

The advantages and disadvantages of CG and VR over non-computerised techniques in a range of user areas have also been discussed. The distinct advantages of CG included editability, repeatability, speed, accuracy, consistency and the ability to visualise complex data without difficulty in both 2D and 3D. Disadvantages included computer fallibility, file incompatibility and the possible user training that is required to operate the software packages. Two of the main advantages of VR are that it can immerse people in an interactive environment that may be unavailable due to cost, safety or perception restrictions, and it is possible to visualise and interact with an environment that may not have been, or cannot be, created in the real environment. The main disadvantages are due to limitations in computer processing power that can lead to either lower frame rates or decreased accuracy in the simulations.

Chapter 3 introduced the field of EIA and current legislation and showed the typical processes involved in the creation of an EIA. VIA was shown to be an important aspect of EIA and current techniques that can be used to aid the development of a VIA were described. A selection of these current techniques have been described in chapter 4 and it was shown that there is scope for improving current VIA techniques. In particular, it was shown that new and improved quantitative techniques are required in order for a more structured and consistent approach towards VIA.

It was ascertained that techniques for assessing visual impact can be broadly split into three groups; spatial, quantitative and qualitative. There are currently only a few VIA techniques that are quantitative, and it is qualitative and spatial methods that tend to be commonly used in VIAs, usually with visualisations and FVIs being predominantly employed. Qualitative approaches, however, may lead to bias due to their inherent subjectivity and spatial methods often require specialist software that often ignore, or cannot accurately model, detailed surface features and this may lead to inaccurate results. Some examples of such software packages were described in chapter 4.

A number of VR software packages and simulations were assessed and a number of key problems were identified. VR simulations, such as the one developed by the Urban Simulation Team, that are accurate and realistic often have the disadvantage of being restricted to running on specialist computer hardware and not being easily distributable due to the VR model's large size. Conversely, VR simulations that can be easily distributed, such as LSS (McCarthy Taylor Systems Ltd., 2002), are often inaccurate due to the inability to incorporate detailed geometric models. This is also reflected in Stock and Bishop's (2002) VR system that also utilises simplistic modelling techniques.

The elevation loss due to the effect of Earth curvature and refraction and the effect of seasonal variation were shown to be of importance in VIAs. It was therefore concluded that the new and

enhanced CG and VR VIA techniques, that were to be developed as part of this research, should be able to incorporate these effects. The importance of using accurate data for the creation of 3D models that are to be used when producing a VIA was also explained, and the German railway project showed the benefit of using laser scanning to quickly produce accurate DEM data.

The quantitative and spatial VIA techniques that have been developed as part of this research have been described in chapter 5. The new and improved techniques, which use 3D CG models that are produced using 3D modelling and animation software, include FVIs, percentage view change analysis, and VR simulations.

Accurate FVIs can be quickly produced without the need for specialist FVI software by using the shadows cast by lights placed at a viewpoint location. Visual changes due to a proposed development can be quantitatively assessed either in real-time using a VR simulation or, more accurately, within a 3D CG modelling environment using the Bitmap Colour Counter utility. A VR methodology has also been developed that combines various VIA techniques into a single environment, where the user has unrestricted access to a proposed development and its surroundings. Techniques to assess the effect of Earth curvature and atmospheric refraction and seasonal variation and growth of vegetation have also been developed.

Chapter 6 presented three case studies that demonstrated some of the new and enhanced techniques that have been developed for use in VIAs and to solve some of the problems associated with computerised VIA techniques that were illustrated in chapter 4.

The Stoke Approach corridor study involved the visualisation of a number of features that were proposed to enhance the overall appearance of the area. Using CG 3D modelling techniques a model of the Hartshill area was produced that was then used to create pre-development and post-development animations from a single key viewpoint. Quantitative analysis, in the form of a percentage view change assessment, was then performed of the view from the critical

viewpoint using the Bitmap Colour Counter utility. The animations were subsequently used to illustrate Babbie Groups' development proposals to members of the Stoke City Council.

The Birmingham university hospital case study was concerned with the development of a new university hospital and the relocation of an existing psychiatric hospital. Using a 3D model of the environment, rendered images, photomontages, animations and percentage view change analyses were performed. A Safe-VR simulation, that integrated some of these results, was also developed. The rendered images, photomontages and percentage view change results were used by Babbie Group as part of an EIS.

The Tiln South case study involved the visual impact analysis of a proposed quarry near the hamlet of Tiln South. The various forms of VIA which were used included rendered images, animations, FVIs and percentage view analysis. The effect of seasonal variation was also investigated. Using Macromedia Director, a VR simulation of the Tiln South environment was created, which integrated rendered images, animations and FVIs that were previously produced. The VR simulation could also determine the percentage view of various features within the environment in real-time.

7.3 Conclusions

7.3.1 Problems With Existing Visual Impact Assessment Techniques

Currently, there are only a few VIA techniques that are quantitative (Zewe and Koglin, 1995 and Pullar and Tidey, 2001). There are also various spatial techniques that exist for VIA, but for the most part, techniques are mainly qualitative since visual impact is concerned with the human appreciation of the landscape (Wherrett, 2002).

The main problem with qualitative techniques in assessing visual impact is that they may lead to bias due to their inherent subjectivity. This inherent subjectivity arises due to the different

experiences, social level and cultural background of the individual assessing the view (Lange, 1994). Indeed, beauty is in the eye of the beholder, and what one person may perceive as a positive visual impact, another may view as negative.

Spatial techniques for the assessment of visual impact differ from both qualitative and quantitative techniques since the results gained from such techniques are neither subjective or quantifiable. However, spatial techniques are often used within a VIA to obtain information regarding which areas can see, or be seen from, a proposed development. FVIs are the most common form of spatial techniques, however various problems with this particular technique do exist.

A number of problems have been identified with current VIA techniques, including; accuracy, length of development time, elevation loss due to Earth curvature and atmospheric refraction, and the effects of seasonal variation and growth of vegetation. Many VIA techniques use CG software packages, with a prime example being GIS. However, the problem with GIS, and other specialist VIA software packages, is that they often do not take into account surface features, and those which do, often represent the features using simple geometrical models that can have a sizeable negative effect on the accuracy of the results.

The FVI, percentage view change and VR techniques have been chosen from the numerous VIA techniques available, and the problems associated with each have been addressed. These techniques have been chosen since it was shown in chapter 3 that there was scope for improving upon their creation, either by enhancing existing methodologies, or developing new methodologies.

The main problems with current FVIs that use DEMs are; accuracy, the time taken to produce, and the specialist software packages often required for their development. The accuracy of an FVI depends upon a number of factors. The DEM needs to be of sufficient precision (by using a

small grid interval) and include the effect of Earth curvature and atmospheric refraction (if the area in question is large enough for the effects to be apparent), detailed surface features (such as buildings and vegetation) and the effects of seasonal variation and growth of vegetation. The time taken to produce an FVI is also important, and this is especially the case when numerous FVIs are required, or if there are a number of different development designs. Currently, in order to produce an FVI, specialist software or a GIS is often required. However, as previously described, these software packages are not designed for accurate, realistic modelling, and hence the results obtained from an FVI may not be reliable.

Techniques specifically designed to efficiently calculate the percentage change in views do not currently exist for VIAs. However, techniques for determining a particular area of an image do exist, but are either crude, time consuming or cannot accurately determine the percentage area of an image feature, such as a tree. This also means that it is currently very difficult to assess percentage views from multiple locations, such as a series of points along a footpath.

The major disadvantage of using a VR system for VIA is accuracy. In order to simulate an interactive environment using real-time rendering, the complexity of the 3D CG model must not exceed the display medium's processing ability. To create an efficient 3D model where real-time rendering is possible, it is necessary to limit the number of faces and the number and size of textures within the model. This can directly affect the accuracy of the simulation. Another possible limitation of VR simulations is that they are considered as a qualitative technique unless combined with spatial and quantitative techniques. Large, complex simulations (which are often the most accurate) can also suffer from distribution problems since they may have large file sizes which cannot be distributed easily over the internet or on CD-ROM, or the simulations may require expensive or specialist hardware in order to render in real-time. Furthermore, there may be a requirement for a software licence in order to run the simulation.

7.3.2 Development of New and Enhanced Techniques

New and enhanced techniques that can be used for VIA have been developed in order to solve many of the problems associated with current techniques, as described above. The techniques use CG technology (including VR) and this enables the advantages of this technology to be integrated into the VIA process. The benefits of using CG for applications such as VIA have been described in chapter 2, but the two distinct advantages of CG that make it useful for VIA are editability and repeatability.

The main focus of this research was to reduce the subjectivity associated with VIA, primarily by developing a new quantitative technique and improving upon existing FVI techniques. Furthermore, it was aimed to develop a VR simulation, that is often considered a qualitative VIA approach, that incorporates both quantitative and spatial techniques. For each of these three goals it was also necessary to be able to include the effects of Earth curvature and atmospheric refraction, and seasonal variation and growth of vegetation.

7.3.2.1 Fields of Visual Influence

A method in which FVIs can be quickly and accurately produced has been developed. The technique uses the concept of light and shadows cast upon a 3D CG model. This methodology can be used for most popular 3D modelling software packages, which means that specialist FVI software or a GIS is not required. The use of a 3D modelling software package also has the advantage of being able to accurately model detailed surface features such as buildings and vegetation.

The new method has been used to produce FVIs for the German railway project and the Tilm South case study. The technique allowed the FVIs to be produced efficiently and accurately, allowing detailed surface features to be catered for, including the use of opacity maps.

7.3.2.2 Percentage View Change Analysis

A technique to determine the percentage view of various features from a user defined viewpoint has been developed. The technique makes use of a software utility called Bitmap Colour Counter, which has been produced using the MAXScripting language of 3D Studio MAX, that determines the percentages of eight different colour groups within a bitmap image.

The new technique can produce very reliable results so long as the 3D model, which is used to create the rendered image used by the utility, is an accurate representation of the environment being modelled. This technique can also assess the percentage view changes which may occur over time, such as vegetative growth, or as the viewing location changes, such as from a series of viewpoints along a footpath.

The percentage view change technique was successfully applied to a number of case studies, and allowed an accurate, quantifiable determination of the of the variation in any view, caused by an existing or proposed development.

Although the method for this particular technique relies upon the Bitmap Colour Counter utility, it is the methodology that is important, not the software itself. Therefore, it is not necessary to have 3D Studio MAX in order to utilise this quantitative VIA technique.

7.3.2.3 Virtual Reality

Two VR simulation techniques were developed during the course of this research. The first approach used Safe-VR, a VR authoring software package developed by Dr. Robin Hollands for AIMS Research at the University of Nottingham, in the UK (Hollands et al, 1999). The Safe-VR simulations, that were developed for the research detailed in this thesis, enabled the integration of results determined from various other VIA techniques, such as FVIs, photomontages and percentage view change analyses. Since the environments within the

simulations were created using a 3D modelling software package, accuracy, detail and realism were achieved, whilst the number of polygons and texture maps was kept to a minimum in order for the simulation to be rendered in real-time.

Due to the inability to freely distribute the simulations and the inability to program new functions within the Safe-VR software environment, a second VR approach was developed using Director Shockwave Studio 8.5, a multimedia authoring software package by Macromedia. The second approach encompassed all the features of the Safe-VR approach, but added the ability to determine the percentage view of features from any viewpoint in real-time, and display pre-determined percentage view results arising from views along set paths running through the environment. It is also possible to freely distribute content that has been created using Macromedia Director Shockwave Studio, either over the internet or on CD-ROM for example. The Tiln South case study, described in chapter 6, used a VR simulation of this type, which enabled the integration of qualitative, spatial and quantitative techniques into a single technique.

7.3.2.4 Effects of Earth Curvature and Atmospheric Refraction

To account for elevation loss due to Earth curvature and atmospheric refraction, a MAXScript utility, called Earth Curver, has been developed. The utility will curve a landscape, within 3D Studio MAX, by vertically lowering a DEMs vertices according to their distance from a specified point of reference. The utility also accounts for the refraction and curvature coefficient that varies with altitude. Another benefit of the Earth Curver utility is that it can be used alongside any VIA technique that uses DEMs, which include FVIs, percentage view change analyses and VR.

The Earth Curver utility was applied to an example environment that featured a proposed development partially screened by some trees from a nearby house. The percentage change in

view of the development after the effects of Earth curvature and atmospheric refraction were applied was negligible. However, this may not be the case for other developments.

7.3.2.5 Seasonal Variation and Growth of Vegetation

Using CG 3D modelling techniques, as described in chapter 5, it is possible to determine the visual impact of a proposed development at various times of the year as vegetation foliage changes, and over time as vegetation grows. The technique is based on using planar objects textured using vegetative bitmaps. By changing the vegetative texture map it is possible to represent different seasons, and by scaling the planar object it is possible to represent different stages of the vegetation's lifetime. This technique does not use complex models consisting of a vast amount of faces, which means that rendering time is kept to a minimum and real-time rendering may be more feasible within VR simulations. Furthermore, this technique does not use complex algorithms to animate the growth of vegetation and this has the benefit of not relying on specialist software packages, many of which use complex 3D vegetation models.

7.3.3 Problems With New and Enhanced Techniques

Although the new and enhanced VIA techniques, which have been developed as part of the research detailed in this thesis, have solved many of the problems associated with current VIA techniques, a number of problems still exist with the new techniques. These problems are discussed below.

7.3.3.1 Fields of Visual Influence

The accuracy of the FVI, produced using the enhanced technique, depends upon the accuracy of the 3D CG models used, with particular reference to DEMs. However, it is commonly known that there are often inaccuracies present within DEMs.

A similar technique, such as that used by Fisher (1994) (described in section 3.3.4.1), can be applied to the 3D CG models that are used by the novel FVI technique described in chapter 5. For example, a probable FVI can be produced by combining FVIs that have been determined using DEMs with different error fields. The probable FVI will provide an estimate of the probability of a location being visible. However, the development of a probable viewshed is beyond the scope of this thesis and is therefore recommended for future research. Further work relating to error modelling has been detailed by the Macaulay Land Use Research Institute (2003).

An additional problem associated with most FVI techniques is that cumulative projective FVIs cannot be accurately produced since the visibility from every point on the exterior of a development must be determined. In order to achieve the utmost reliability of results using the enhanced technique, as many omni lights as possible would have to be placed on the exterior of a development model. This would directly increase computer processing time and could become impractical.

7.3.2.2 Percentage View Change Analysis

The percentage view change analysis technique uses a utility, called Bitmap Colour Counter, that has been developed using MAXScript, which has a direct disadvantage in that it requires 3D Studio MAX to function. Furthermore, the Bitmap Colour Counter can currently only distinguish between eight colours, which means only eight different features within a 3D model or image can be assessed. However, the number of features that can be analysed can be increased by increasing the number of colour categories.

As with the enhanced FVI technique, the results obtained from the percentage view analysis technique relies upon the accuracy of the 3D CG model used. Using a technique similar to Fisher's (1994), a probable percentage view change analysis can be performed by averaging the

results from several assessments that have been based upon DEMs with different error fields.

Although this technique can quantitatively determine the percentage change in view due to a proposed development, the size of this change that constitutes an acceptable or unacceptable impact is still unknown. The studies performed by Stamps (1992), Watzek and Ellsworth (1994) and Lange (2001) (see section 3.3.4.3) show that it may be possible, by showing numerous sets of pre and post development images to a number of respondents, to determine the approximate percentage view change values that constitute acceptable and unacceptable changes in view due to a proposed development. For example, it could be determined that a four percent decrease in vegetation is the cut off value between an acceptable and unacceptable visual impact.

The probable percentage view change analysis and significant percentage change techniques that have been suggested above are beyond the scope of this thesis and it is therefore recommended that they are researched further.

7.3.2.3 Virtual Reality

The major problem associated with the integrated VR simulation technique is accuracy, which depends upon a number of factors, namely the accuracy of the 3D model initially created and the processing power of the computer used to run the simulation. If the computer has a limited amount of processing power then in order to achieve real-time rendering the number of faces within the model will have to be limited, which may directly affect the accuracy of the simulation. However, if Moore's Law, which states that computer technology will double in capacity every eighteen months (Sieg, 1997), holds true then real-time rendering will become possible for even the most complex of 3D models within a VR environment.

7.3.2.4 Effects of Earth Curvature and Atmospheric Refraction

The accuracy of a DEM that has been modified using the Earth Curver utility depends upon the

number and spacing of the vertices within the DEM. Increased accuracy will be derived by adding more vertices and by spacing the vertices so that they are not too far apart from each other. Currently, the utility is limited to average UK temperatures, but can be modified to include numerous temperature variables if required. As with the Bitmap Colour Counter utility, used to assess percentage view changes, the Earth Curver runs within the 3D Studio MAX software environment, which limits its use.

7.3.2.5 Seasonal Variation and Growth of Vegetation

The major problem with the new technique for accounting for seasonal variation and growth of vegetation is that realistic and accurate texture maps are required for the planar objects that represent the vegetation. In particular, accurate vegetative texture maps may be required for each of the four seasons and as the vegetation grows over time. A high level of accuracy may be obtained by using photographs of similar vegetative specimens as they change through the seasons and over time.

7.4 Recommendations

A number of potential problems with the new and enhanced VIA techniques have been discussed above and a number of possible solutions have been suggested. However, there are still a number of improvements that could be made to the techniques that will require further research and development and these are suggested below.

A technique is required that can accurately produce cumulative projective FVIs. The creation of accurate cumulative FVIs is a problem using current techniques. The use of area lights (described in chapter 2) within a 3D CG model is one possible solution to this problem, although further research will be required.

The development of alternative Bitmap Colour Counter and Earth Curver utilities that run as

stand-alone programs is suggested by the author. This would allow the new VIA techniques to be applied without the requirement of 3D Studio MAX. The programming language C++ could be used to develop such tools.

Further research is required to determine the most appropriate aspect ratio and camera lens when assessing percentage change in views. The aspect ratio and camera lens should represent the human field of view as best as possible for accurate results. It is currently accepted to use a camera lens with a focal length of between 50 and 65mm (IEATLI, 1995). However, determining the correct aspect ratio may be difficult since the human field of view is 200 degrees horizontally and 135 degrees vertically (Atherton, 2003).

A further recommendation is that the new and enhanced techniques, which have been developed as part of the research detailed in this thesis, should be tied in with landscape evaluation in order to make this currently subjective technique more objective by using quantifiable methods.

7.5 Concluding Remarks

This research aimed to improve upon existing, and develop new, techniques for the assessment of visual impact in a less subjective manner, using CG and VR techniques. A new method for creating FVIs has been developed and has been used in numerous case studies illustrated within this thesis. A quantitative technique, in the form of percentage view change analysis, has also been developed and a number of case studies have been shown that illustrate the technique. Furthermore a VR simulation technique has been created that integrates many forms of qualitative, spatial and quantitative VIA techniques. The effects of Earth curvature and atmospheric refraction, and seasonal variation and growth of vegetation have also been shown and techniques developed to account for them.

8 References

3D Cafe. *3D Cafe's Free 3D Models Meshes* [online]. Platinum Pictures Multimedia, Inc., 2003. Available at: <<http://www.3dcafe.com/asp/meshes.asp>> [27 January 2003].

3D Laser Mapping Ltd. *Industrial Applications* [online]. 3D Laser Mapping Ltd., 2001a. Available at: <<http://www.3dlasermapping.com/industrial.htm>> [05 August 2002].

3D Laser Mapping Ltd. *Survey and GIS Applications* [online]. 3D Laser Mapping Ltd., 2001b. Available at: <<http://www.3dlasermapping.com/survey.htm>> [05 August 2002].

About, Inc. *Computer Graphics* [online]. 2002. Available at: <<http://3dgraphics.about.com/library/glossary/bldef-CG.htm>> [05 September 2002].

Adobe Systems Inc. *Adobe* [online]. 2003. Available at: <<http://www.adobe.com>> [20 February 2003].

Aerospace Industries. *SU-22 M4 bomber full flight simulator* [online]. 2002. Available at: <http://www.ai.com.pl/ai_eng/Izolda.htm> [08 October 2002].

AIMS Research. *AIMS Research* [online]. 2002. Available at: <<http://www.nottingham.ac.uk/aims/>> [30 September 2002].

AIMS Solutions Ltd. *AIMS Solutions* [online]. 2002. Available at: <<http://www.aims-solutions.co.uk>> [05 February 2002].

Aldex Software Ltd. *LandCalc* [online]. Aldex Software, 1999. Available at: <<http://www.aldex.co.uk/landcalc.html>> [29 July 2002].

Alias/Wavefront. *Maya* [online]. 2002. Available at:
<<http://www.aliaswavefront.com/en/products/maya/index.shtml>> [07 October 2002].

Animetix Technologies, Inc. *Animetix Technologies, Inc* [online]. 2001. Available at:
<<http://www.animetix.com/>> [15 October 2002].

Appleton, K., Lovett, A., Sunne nberg, G. and Dockerty, T. Rural landscape visualisation from GIS databases: a comparison of approaches, options and problems. *Computers, Environment and Urban Systems*. 2002, Vol. 26, pp. 141-162.

Arnett, B. *Earth* [online]. 5th May 2002. Available at:
<<http://www.seds.org/nineplanets/nineplanets/earth.html>> [03 September 2002].

Arthur, L.M., Daniel, T.C. and Boster, R.S. Scenic Assessment: An Overview. *Landscape Planning*, 1977, Vol. 4, pp.109-129. Cited in Wherrett (1998).

Artifice, Inc. *Design Workshop* [online]. 2003. Available at:
<<http://www.artifice.com/gallery.html>> [15 April 2003].

Atherton, T. *Computer Graphics* [online]. 2003. Available at:
<<http://www.dcs.warwick.ac.uk/~tja/Campus/CS324/CompGraph.html>> [14 May 2003].

Atlas Computers Ltd. *SCC – ZVI* [online]. 2000. Available at:
<<http://www.atlascomputers.ie/scc-ZVI.htm>> [24 July 2002].

Autodesk, Inc. *Online Reference*. 3D Studio MAX R3.1 help file, 1999.

Autodesk, Inc. *3D Studio VIZ* [online]. 2002a. Available at:

<<http://www.discreet.com/products/products.html?prod=3dsviz>> [24 July 2002].

Autodesk, Inc. *3DS MAX* [online]. 2002b. Available at:

<<http://www.discreet.com/products/3dsmax>> [30 July 2002].

Autodesk, Inc. *AutoCAD* [online]. 2002c. Available at:

<<http://www.autodesk.co.uk/adsk/section/0,,1075861-452932,00.html>> [07 October 2002].

Autodesk, Inc. *Autodesk Map* [online]. 2002d. Available at:

<<http://www.autodesk.co.uk/adsk/section/0,,2290399-452932,00.html>> [01 November 2002].

Autodesk, Inc. *Autodesk Land Desktop* [online]. 2002e. Available at:

<<http://www.autodesk.co.uk/adsk/section/0,,821659-452932,00.html>> [18 November 2002].

Aylward, G. and Turnbull, M. Visual analysis: a computer-aided approach to determine visibility. *Computer-Aided Design*, 1977, Vol. 9, No. 2, pp.103-108.

Babtie Group. Personal Communication (February, 2000a).

Babtie Group. *Stoke Approach Corridor Study Final Report*. Unpublished (2000b).

Babtie Group. Personal Communication (May, 2000c).

Banta Corporation. *Technovation Exchange Handbook*, Fifth Edition [online]. 2001. Available at: <<http://www.banta.com/tech/handbook/>> [09 September 2002].

Beier, K.P. *Virtual Reality: A Short Introduction* [online]. 29 September 2001. Available at: <<http://www-vrl.umich.edu/intro/>> [17 September 2002].

Bentley Systems Inc. *MicroStation* [online]. 2002. Available at: <<http://www.bentley.com>> [07 October 2002].

Bergen, S.D. *Mitigating Potential Impact to Visual Quality During the Design of Forest Operational Plans* [online]. 1993. Available at: <<http://forsys.cfr.washington.edu/~vp/Papers/Bergen.html>> [24 July 2002].

Berney, A. *Horizons – Interactive visual impact analysis* [online]. 2000. Available at: <<http://www.hemes.net/Maggie/aaron/horizons/index.html>> [24 July 2002].

Bishop, I. *Viewshed Analysis*. [online]. 2002. Available at: <http://www.sli.unimelb.edu.au/cgism/GISA/visibility_files/frame.htm> [03 September 2002].

Bond, A. *Environmental Impact Assessment in the UK*. Oxford: Chandos Publishing (Oxford) Ltd, 2000.

British Medical Association. *Health & Environmental Impact Assessment – An Integrated Approach*. London: Earthscan Publications Ltd, 1998.

Brush, R.O. and Shafer, E.L. Application of a Landscape-Preference Model to Land Management. In: Zube, E.H., Brush, R.O. and Fabos, J.G., eds. *Landscape Assessment: Values, Perceptions and Resources*. Pennsylvania: Halstead Press, 1975.

Buhyoff, G.J., Miller, P.A., Roach, J.W., Zhou, D. and Fuller, L.G. An AI Methodology for Landscape Visual Assessments. *AI Applications*. 1994, Vol. 8, pp. 1-13. Cited in Wherrett (1998).

Bulmer, D. How can computer simulated visualizations of the built environment facilitate better public participation in the planning process? *Online Planning Journal* [online], 13 November 2001. Available at:
<<http://www.casa.ucl.ac.uk/planning/articles61/complanning.pdf>> [05 August 2002].

Burton, A. Personal Communication (2002).

Carnegie Mellon University. *Alice* [online]. 1999. Available at: <<http://www.alice.org/>> [14 October 2002].

Chester, T. *The Effect Of Atmospheric Refraction On The Observed Elevation Angles Of Peaks* [online]. 11 Apr 1999. Available at:
<http://sd.znet.com/~schester/angeles_mtns/tables/refraction.html> [03 September 2002].

Corel Corporation. *Corel* [online]. Available at: <<http://www3.corel.com>> [07 October 2002].

Cox, C. *The Use of Computer Graphics to Visual Impact Assessment*. BEng dissertation, University of Nottingham, 1999.

Cox, C. and Schofield, D. Visual Impact Assessment, a Quantitative Computer Based Method, *Proceedings of ENVSOFT 2002: The Ninth International Conference on The Modelling, Monitoring and Management of Environmental Problems*, Bergen, Norway, 6th – 8th May 2002.

Daniel, T.C. and Boster, R.S. Measuring Landscape Aesthetics: The Scenic Beauty Estimation Method. *USDA Forest Service Research Paper RM-167*. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, CO., 1976, pp. 66. Cited in Bergen (1993).

Daniel, T.C. and Vining, J. Methodological Issues in the Assessment of Landscape Quality. *In: Altman, I. And Wohlwill, J.F., eds. Behaviour and the Natural Environment*. Vol. 6. New York: Plenum Press, 1983, pp.39-84. Cited in Bergen (1993) and Wherrett (1998).

Dark Basic Software Ltd. *DarkBASIC* [online]. 2002. Available at: <<http://www.darkbasic.com/>> [14 October 2002].

Department of the Environment. *Environmental Assessment: A Guide to the Procedures*. London: HMSO, 1989. Cited in British Medical Association (1998).

Development Planning & Design Services (DPDS). *Non-Technical Summary* [online]. 2001. Available at: <http://www.leavesdenpark.com/plan_frame.html> [10 May 2002].

DOEWO (Department of the Environment Welsh Office). *Environmental Assessment – A guide to the Procedures*. London: HMSO, 1990.

Dougherty, T.C. and Hall, A.W. *Environmental Impact Assessment of Irrigation and Drainage Projects* [online]. 1995. Available at: <<http://www.fao.org/docrep/V8350E/v8350e00.htm#Contents>> [30 April 2002].

E-on Software. *Vue D'Esprit 4* [online]. Available at: <<http://www.e-onsoftware.com/Products/VueIndex.php>> [07 October 2002].

Environment Agency. Press Release. May 2002.

EON Reality, Inc. *EON Reality Inc* [online]. Available at: <<http://www.eonreality.com/>> [14 October 2002].

ESRI. *ArcInfo* [online]. 2002. Available at:
<<http://www.esri.com/software/arcgis/arcinfo/index.html>> [29 July 2002].

ESRI. *ArcView* [online]. 2003a. Available at:
<<http://www.esri.com/software/arcgis/arcview/index.html>> [13 February 2003].

ESRI. *ArcGIS 3D Analyst* [online]. 2003b. Available at:
<<http://www.esri.com/software/arcgis/arcgisxtensions/3danalyst/index.html>> [13 February 2003].

European Commission. *Guidance on EIA – EIS Review* [online]. Luxembourg: Office for official publications of the European communities, 2001. Available at:
<<http://europa.eu.int/comm/environment/eia/eia-guidelines/g-review-full-text.pdf>> [30 April 2002].

Evans & Sutherland. *Virtual Environments for Real-Time Display* [online]. 2002a. Available at: <<http://www.es.com/products/database+modeling+systems/easiest/index.asp>> [14 October 2002].

Evans & Sutherland. *Simulation Software for Symphony Products* [online]. 2002b. Available at: <<http://www.es.com/products/database+modeling+systems/integrator/index.asp>> [14 October 2002].

Felleman, J.P. Visibility mapping in New York's coastal zone: A case study of alternative methods. *Coastal Zone Management Journal*, 1982, Vol. 9, No. 3, pp. 249-270. Cited in Wood (2000).

Fels, J.E. Viewshed simulation and analysis: an interactive approach. *GIS World*, July 1992, 54-59. Cited in Wherrett, 1998.

Fisher, P.F. First experiments in viewshed uncertainty: Simulating the fuzzy viewshed. *Photogrammetric Engineering & Remote Sensing*, 1991, Vol. 57, pp.1321-1327. Cited in Wang *et al.*, 1996.

Fisher, P.F. Algorithm and implementation uncertainty in viewshed analysis. *Int. J. Geographical Information Systems*, 1993, Vol. 7, No. 4, pp. 331-347.

Fisher, P.F. Probable and fuzzy models of the viewshed operation. *In: Worboys, M.F., ed. Innovations in GIS: selected papers from the First National Conference on GIS Research UK.* 1994, pp. 161-175.

Fisher, P.F. Extending the Applicability of Viewsheds in Landscape Planning. *Photogrammetric Engineering & Remote Sensing*, Nov 1996, Vol. 62, No. 11, pp.1297-1302.

Foley, J.D, van Dam, A., Feiner, S.K., Hughes, J.F. and Phillips, R.L. *Introduction to Computer Graphics.* Wokingham: 1994.

Floriani, L.D., Falcidieno, B., Pienovi, C., Allen, D. and Nagy, D. A visibility-based model for terrain features. *Proceedings of 2nd International Symposium on Spatial Data Handling.* Seattle, Washington, 1986, pp. 235-250. Cited in Wang *et al.*, 1996.

Freefoto, Inc. *Freefoto.com* [online]. 2002. Available at: <<http://www.freefoto.com>> [10 February 2003].

Ghadirian, P. and Bishop, I.D. Composition of Augmented Reality and GIS to Visualize Environmental Changes. *Proceedings from the Joint AURISA and Institution of Surveyors Conference*. Adelaide, South Australia, 2002.

Gilpin, A. *Environmental Impact Assessment – Cutting Edge for the Twenty-First Century*. Cambridge: Cambridge University Press, 1995.

GIMP. *The Gimp* [online]. 2002. Available at: <<http://www.gimp.org>> [07 October 2002].

Glinert, S. *Macromedia Director 8.5 Enters the Third Dimension* [online]. 13 June 2001. Available at: <<http://www.creativepro.com/story/review/13540.html>> [13 January 2003].

Golf-a-Round America. *How Real Is It?* [online]. Available at: <<http://www.golfaroundamerica.com/features.html>> [08 October 2002].

Goodchild, M.F. and Lee, J. The coverage problem and visibility regions on topographic surface. *Annals of Operations Research*, 1989, Vol. 18, pp.235-250. Cited in Wang *et al.*, 1996.

Graphisoft. *ArchiCAD* [online]. 2002. Available at: <http://www.graphisoft.com/products/architecture_and_design/graphisoft_archicad/> [07 October 2002].

Gray Matter Interactive Studios. *Return to Castle Wolfenstein* [online]. 2002. Available at: <<http://www.activision.com/games/wolfenstein/>> [17 September 2002].

Gross, J.S. Personal Communication (28th Sep 2000).

Hollands, R., Denby, B., Schofield, D., Brooks, G. and Burton, A. Use of Virtual Reality in Improving Safety Awareness and Performance. *Proceedings of the Offshore Safety Conference*, Perth, Australia, 1999.

Hopkinson, P. G. *What is EIA?* [online]. Bradford: Hopkinson, 1997. Available at: <<http://www.brad.ac.uk/staff/pghopkin/whatissea.html>> [30 April 2002].

IEATLI (Institute of Environmental Assessment and The Landscape Institute). *Guidelines for Landscape and Visual Impact Assessment*. 1st Edition. London: E & FN Spon, 1995.

Immersive Systems Inc. *Meme* [online]. Available at: <<http://www.immersive.com/>> [14 October 2002].

IMSI. *TurboCAD* [online]. 2002. Available at: <<http://www.turbocad.com>> [07 October 2002].

Itami, R.M. and Raulings, R.J. *SAGE Introductory Guidebook*. Melbourne, Australia: DLSR, 1993.

Ito Software. *Forest Pack* [online]. 2002. Available at: <<http://www.itoosoft.com>> [05 November 2002].

Jackson, B. and Leong, C. Levelling. In: Wilson, L.E.L., ed. *Caltrans LS/LSIT Video Exam Preparation Course* [online]. California: Caltrans Geometronics, 1993, Chpt. 6, pp. 4. Available at: <<http://www.dot.ca.gov/hq/esc/geometronics/LSITWorkbook/06.pdf>> [03 September 2002].

Jasc Software. *Welcome to Paint Shop Pro 7.* Paint Shop Pro 7 help file, 2000.

Jasc Software. *Jasc Paint Shop Pro 7 Anniversary Edition* [online]. 2002. Available at:
<<http://www.jasc.com/products/psp/>> [07 October 2002].

Jepson, W., Liggett, R. and Friedman, S. An Environment for Real-time Urban Simulation.
Proceedings of the Symposium on Interactive 3D Graphics, Monterey, California, April 1995.

Kalawsky, R.S. *Exploiting Virtual Reality Techniques in Education and Training: Technological Issues* [online]. 2000. Available at:
<<http://www.agocg.ac.uk/reports/virtual/vrtech/title.htm>> [30 September 2002].

Kerlow, I.V. *The Art of 3-D Computer Animation and Imaging.* 2nd Edition. Chichester: John Wiley & Sons, Inc., 2000.

KeyTERRA-FIRMA Ltd. *Ground Modelling* [online]. Available at: <<http://www.keyterra-firma.com/gmod.shtml>> [13 June 2002].

Lange, E. Integration of computerized visual simulation and visual assessment in environmental planning. *Landscape and Urban Planning*, 1994, Vol. 30, pp. 99-112.

Lange, E. The limits of realism: perceptions of virtual landscapes. *Landscape and Urban Planning*, 2001, Vol. 54, pp. 163-182.

LITIEMA (The Landscape Institute and the Institute of Environmental Management and Assessment). *Guidelines for Landscape and Visual Impact Assessment.* 2nd Edition. London: Spon Press, 2002.

Macaulay Land Use Research Institute. *Geographic Error Modelling* [online]. 2003. Available at: <<http://www.mluri.sari.ac.uk/ccw/task-four/geogerror/geogerror.html>> [09 July 2003].

Macromedia, Inc. *Macromedia Director 8.5 Shockwave Studio* [online]. 2002. Available at: <<http://www.macromedia.com/software/director/>> [14 October 2002].

March, J. Personal Communication (2003).

McCarthy Taylor Systems Ltd. *LSS Digital Terrain Modelling Software* [online]. 2002. Available at: <<http://www.mccarthytaylor.com>> [24 October 2002].

McCloy, R. and Stone, R. Virtual reality in surgery. *BMJ*, 2001, Vol. 323, pp. 912-915.

Meitner, M.J. and Daniel, T. C. Vista Scenic Beauty Estimation Modelling: A GIS Approach. *1997 ESRI International User Conference* [online], 8th July 1997. Available at: <<http://gis.esri.com/library/userconf/proc97/proc97/to250/pap202/p202.htm>> [29 July 2002].

Mischler, G. *Lighting Design Knowledgebase* [online]. Available at: <http://www.schorsch.com/kbase/glossary/solid_angle.html> [24 July 2002].

Multimap. *Multimap* [online]. Available at: <<http://www.multimap.com/>> [17 January 2003].

Nakamae, E., Qin, X. and Tadamura, K. Rendering of landscapes for environmental assessment. *Landscape and Urban Planning*, 2001, Vol.54, pp. 19-32.

Nasios, K. *Improving Chemical Plant Safety Training Using Virtual Reality*. Ph.D. thesis, University of Nottingham, 2001.

NewTek. *Lightwave 7.5* [online]. 2002. Available at: <<http://www.lightwave3d.com/>> [07 October 2002].

Nickerson, D.B. SIGHTLINE, PERSPECTIVE PLOT, SCOPE – Three Desktop Computer Programs for Forest Landscape Design. *Journal of Forestry*, 1979, Vol. 77, No. 1, pp. 14-17.

NCDOT (North Carolina Department of Transportation). *Electronic Field Book Processing Technical Documentation* [online]. Available at: <http://www.doh.dot.state.nc.us/preconstruct/highway/location/support/Support_Files/Documents/Manuals/efbt.pdf> [03 September 2002].

Oh, K. LandScape Information System: A GIS approach to managing urban development. *Landscape and Urban Planning*, 2001, Vol. 54, pp. 79-89.

Onlineconversion. *Length Conversion* [online]. 2002. Available at: <<http://www.onlineconversion.com/length.htm>> [03 September 2002].

Ordnance Survey. *Glossary* [online]. 2001a. Available at: <<http://www.ordsvy.gov.uk/literatu/info/glossary.htm>> [16 October 2002].

Ordnance Survey. *LIDAR* [online]. 2001b. Available at: <<http://www.ordsvy.gov.uk/productpages/lidar/home.htm>> [05 August 2002].

P & I Design Ltd. *Disperse – Air Pollution Modelling Tool* [online]. Cleveland: P & I Design Ltd., 1999. Available at: <<http://www.pidesign.co.uk/Mn101a.pdf>> [28 May 2002].

Pixar. PIXAR [online]. 2002. Available at: <<http://www.pixar.com>> [07 October 2002].

Platt, L.T. *Assessing the Cumulative Environmental Impact from Surface Mining Operations*. Ph.D. thesis, The University of Nottingham, Nottingham, 2002.

Polytechnic. *Air Pollution Transport Teaching Modelling* [online]. Available at: <http://cities.poly.edu/environment/gradedu/ce752/ce752_airmodeling.html> [15 April 2003].

Pullar, D.V. and Tidey, M.E. Coupling 3D visualisation to qualitative assessment of built environment designs. *Landscape and Urban Planning*, 2001, Vol. 55, pp. 29-40.

Roberts, G.W, Evans, A., Dodson, A., Denby, B., Cooper, S. and Hollands, R. Look Beneath the Surface with Augmented Reality [online]. *GPS World*, 31 January 2002. Available at: <<http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=9516#>> [14 October 2002].

Sansoni, C. Visual analysis: a new probabilistic technique to determine landscape visibility. *Computer-Aided Design*, 1996, Vol. 28, No. 4, pp. 289-299.

SAVE. *The Head Mounted Display (HMD)* [online]. 2000. Available at: <<http://www.faw.unilinz.ac.at/save/>> [08 October 2002].

Scan-UK. *Environmental Impact Assessment* [online]. Manchester: Scan-UK, 2000. Available at: <<http://www.scan-uk.mmu.ac.uk/Topics/eia.html>> [30 April 2002].

Schofield, D. *Virtual Reality for Engineers*. Lecture notes, University of Nottingham, 2000.

Sense8. *WorldToolKit* [online]. 2001. Available at: <<http://www.sense8.com/products/index.html>> [14 October 2002].

Shafer, E.L., Hamilton, J.F. and Schmidt, E.A. Natural landscape preferences: a predictive model. *Journal of Leisure Research*. 1969, Vol. 1, pp. 1-19. Cited in Bergen (1993) and Wherrett (1998).

SICS. DIVE [online]. Available at: <<http://www.sics.se/dive/dive.html>> [14 October 2002].

Sorenson, A.P. and David, L.P. Two algorithms for determining partial visibility and reducing data structure induced error in viewshed analysis. *Photogrammetric Engineering & Remote Sensing*, 1993, Vol. 59, pp.1149-1160. Cited in Wang *et al.*, 1996.

Sieg, D. Moore's Law Still Holds! [online]. 30 November 1997. Available at: <<http://www.davesraves.com/Features/moores1.html>> [09 May 2003].

Sparkes, A. and Kidner, D. *A GIS for the Environmental Impact Assessment of Wind Farms* [online] 2nd October 1996. Available at: <<http://gis.esri.com/library/userconf/europroc96/PAPERS/PN26/PN26F.HTM>> [30 July 2002].

Stamps, A. E. III. Perceptual and preferential effects of photomontage simulations of environments. *Perceptual and Motor Skills*, 1992, Vol. 74, pp. 675-688.

Superscape. Company Info [online]. 2001. Available at: <<http://www.superscape.com/company/index.asp>> [14 October 2002].

Tarmac Quarry Products Limited. Personal Communication with AIMS Research (1993).

Terrasolid Ltd. Available Products [online]. 2002. Available at: <<http://www.terrasolid.fi/ENG/Products.htm>> [18 November 2002].

Themekit Systems Ltd. *Themekit Systems – Virtual Reality Software* [online]. 2000. Available at: <<http://www.themekit.com/>> [14 October 2002].

TJP Envision Ltd. *Seeing your world* [online], 2001. Available at: <<http://www.envision.ltd.uk/index.htm>> [30 July 2002].

Transport Research Laboratory. Personal communication (2002).

Travis, M.R., Elsner, G.H., Iverson, D. and Johnson, C.G. *VIEWIT: Computation of Seen Areas, Slope and Aspect for Land-Use Planning*. Technical Report, UDSA Forest Service, 1975, (PSW-11/1975). Cited in Wang *et al.*, 1996 and Bergen, 1993.

University of Melbourne. *Plane Surveying* [online], 12 June 1999. Available at: <<http://www.sli.unimelb.edu.au/planesurvey/prot/>> [02 September 2002].

Urban Simulation Team. *Urban Simulation Team* [online]. Available at: <<http://www.ust.ucla.edu/ustweb/ust.html>> [22 October 2002].

U.S. Geological Survey. *Geographic Information Systems* [online]. 19 August 2002. Available at: <<http://info.er.usgs.gov/research/gis/title.html>> [07 November 2002].

Vallino, J. *Augmented Reality Page* [online], 28 May 2002. Available at: <<http://www.se.rit.edu/~jrv/research/ar/introduction.html>> [19 September 2002].

Van Dam, A. *Introduction to Computer Graphics* [online]. 5 September 2002. Available at: <<http://www.cs.brown.edu/courses/cs123/lectures/Introduction.pdf>> [05 September 2002].

Vince, J. *Essential Virtual Reality Fast*. London: Springer, 1998.

Vince, J. *Virtual Reality Systems*, ACM SIGGRAPH Book Series. Wokingham: Addison-Wesley Publishing Company, 1995.

Wang, J., Robinson, G.J. and White, K. A Fast Solution to Local Viewshed Computation Using Grid-Based Digital Elevation Models. *Photogrammetric Engineering & Remote Sensing*, Oct 1996, Vol. 62, No. 10, pp.1157-1164.

Ward, T. *Noise Visualisation*. Third year dissertation, University of Nottingham, 2002.

Wathern, P. (ed.). *Environmental Impact Assessment: Theory and Practice*. London: Routledge, 1988. Cited in Dougherty and Hall, 1995.

Watson, D. *Using Co-ordinates* [online]. 2002. Available at:
<<http://www.cadtutor.net/acad/acad2ki/coords/coords.html>> [15 October 2002].

Watt, A. *3D Computer Graphics*. 3rd Edition. London: Addison-Wesley Publishing Ltd., 2000.

Watzek, K.A. and Ellsworth, J.C. Perceived Scale Accuracy of Computer Visual Simulations. *Landscape Journal*, 1994, Vol. 13, No. 1, pp. 21-36.

Wherrett, J.R. *Cumulative Impact of Wind Turbines* [online]. Aberdeen: The Macaulay Institute. Available at: <<http://www.mluri.sari.ac.uk/ccw/>> [30 April 2002].

Wherrett, J.R. *Natural Landscape Scenic Preference: Techniques for Evaluation and Simulation*. Ph.D. thesis (unpublished), Robert Gordon University, Aberdeen, 1998.

Williams, M.J. *Application of Virtual Reality for Risk Assessment and Training in the Minerals Industry*. Ph.D. thesis, University of Nottingham, 2000.

Wood, G. Is what you see what you get? Post-development auditing of methods used for predicting the zone of visual influence in EIA. *Environmental Impact Assessment Review*, 2000, Vol. 20, pp. 537-556.

Young, G.G. and Lemkow, D.Z. Digital terrain simulators and their application to forest development planning. *Proceedings of the 1976 Skyline Logging Symposium*, pp.81-99, 1976. Cited in Bergen, 1993.

Zewe, R. and Koglin, H.J. A method for the visual assessment of overhead lines. *Computers and Graphics*, 1995, Vol. 19, No. 1, pp. 97-108.

Appendix 1: Software Used

A1.1 Introduction

Six pieces of software have been primarily used to develop the new techniques and to create the various case studies and example projects and these are; AutoCAD, 3D Studio MAX, Paint Shop Pro, Safe-VR, Macromedia Director Shockwave Studio and CorelDRAW. It should be noted that the new VIA techniques do not solely rely on these software packages and other similar packages could be used. The various software packages that have been used are described below.

A1.2 AutoCAD

Autodesk's AutoCAD is a popular CAD software package used in many different industrial sectors from architects to draughtsmen. AutoCAD (version R14) is made use of in many of the case studies and example projects presented later in this thesis. It has been primarily used to manipulate raw survey data, often provided in DXF and DWG drawing file formats, that were obtained from the project partners, so that the data could be easily imported into 3D Studio MAX. AutoCAD 2002 and 2002LT currently retail at approximately £3500 and £675 respectively. Other less expensive CAD packages which can handle DXF and DWG drawing file formats could have been used equally as well.

A1.3 3D Studio MAX

Discreet's 3D Studio MAX is a 3D CG modelling and animation software package used to quickly create professional-quality 3D models, photo-realistic still images, and film-quality animation on a desktop computer. For the case studies and project examples shown in this thesis, 3D Studio MAX R3.1 has been used. The choice of this software was due to its availability, familiarity and its MAXScripting language which is described below. Currently,

commercial versions of 3D Studio MAX R5 retail for approximately £2700.

A1.3.1 MAXScripting

MAXScript is the built-in scripting language for 3D Studio MAX and provides the ability to (Autodesk, Inc., 1999):

- ?? Script all aspects of 3DS MAX use, such as modelling, animation, materials and rendering.
- ?? Control 3DS MAX interactively through a command-line shell window.
- ?? Package scripts within custom utility panel rollouts or modeless windows, giving them a standard 3DS MAX user interface.
- ?? Build custom import and export tools using the built-in file input and output interface.
- ?? Write procedural controllers that can access the entire state of the scene. Build batch-processing tools, such as batch-rendering scripts.

Autodesk, Inc. (1999) also state:

“The MAXScript language is specifically designed to complement 3D Studio MAX. It is object-oriented, just like 3DS MAX, and has several special features and constructs that mirror high-level concepts in the 3DS MAX user interface. These include coordinate-system contexts, an animation mode with automatic keyframing, and access to scene objects using hierarchical path names that match the 3DS MAX object hierarchy. The syntax is simple enough for non-programmers to use, with minimal punctuation and formatting rules.”

MAXScripting has been used to develop 3D Studio MAX plug-in software utilities that aim to improve upon existing techniques and to create new techniques for VIA. The utilities developed are described in detail later in this chapter.

A1.3.2 Forest Pro Plug-in

Forest Pro is a plug-in utility for 3D Studio MAX developed by Itoo Software (2002) which is designed for the creation of large groups of trees and plants. The trees are created as textured planar objects which require modest resources and can therefore be rendered quickly. Figure A1.1 shows the difference between a 2D planar tree compared to a 3D multi-faced tree model. The planar tree not only looks more realistic, but also only has two faces compared with the 10908 faces of the 3D tree.

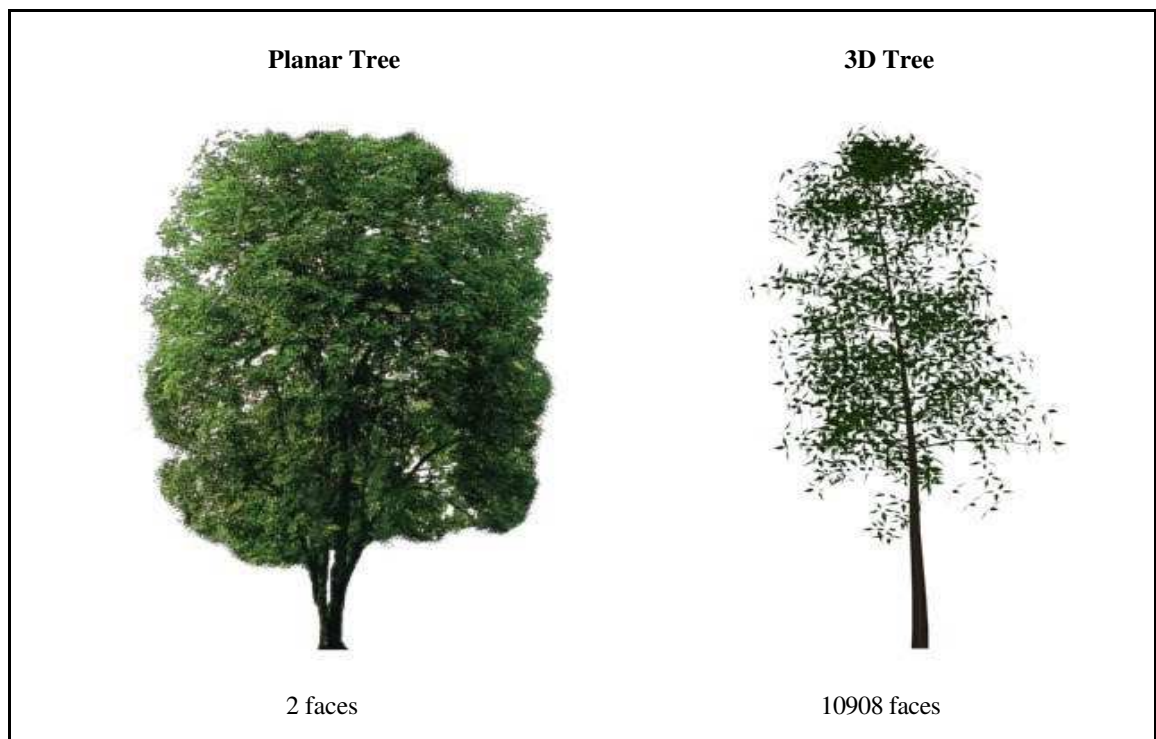


Figure A1.1: Planar trees versus 3D multi-faced trees¹⁹⁰.

Splines are used to define the areas to plant the trees and bitmap images can be used to define the distribution patterns of the trees. The trees can also be linked to a camera so that they will always be facing the viewer if the camera is moved. Packaged with Forest Pro is another plug-in called “Planes”, which is similar to Forest Pro except that it creates single individual plane objects instead of groups. Forest Pro currently retails at approximately £130.

¹⁹⁰ 3D tree model from 3D Cafe (2003), images by the author (January 2003).

A1.4 Paint Shop Pro

Jasc Software's Paint Shop Pro 7 is an image editing software package and Jasc Software (2000) state:

“Jasc Paint Shop Pro 7 contains all the tools you need for creating, editing, and retouching your images. It is friendly enough for the casual user who wants to enhance family photographs, yet powerful enough for the professional who needs to create multi-layered graphics.”

Paint Shop Pro has been used to create and edit textures for the geometry modelled in 3D Studio MAX. The software is designed for both novice and professional users and retails at under £100. Paint Shop Pro was chosen because of its ease of use and its low cost.

A1.5 Safe-VR

Safe-VR is a VR authoring software package developed by Dr. Robin Hollands for AIMS Research at the University of Nottingham, in the UK (Hollands et al, 1999). The main use of Safe-VR is as a training and hazard awareness system, but its versatility allows it to be used in a number of other fields including environmental visualisation and accident reconstruction. Figure A1.2 shows a screenshot of a construction site hazard spotting exercise, produced by AIMS Research, which was developed using Safe-VR.

Safe-VR provides a user friendly graphical user interface application development tool to perform a number of functions, including:

- ?? Generation of a 3D representation of a working environment.
- ?? Freedom to move around within the environment but with set boundaries.
- ?? Interaction with objects, such as the operation of equipment.
- ?? Placement of hazardous objects that the user must find, identify and treat.

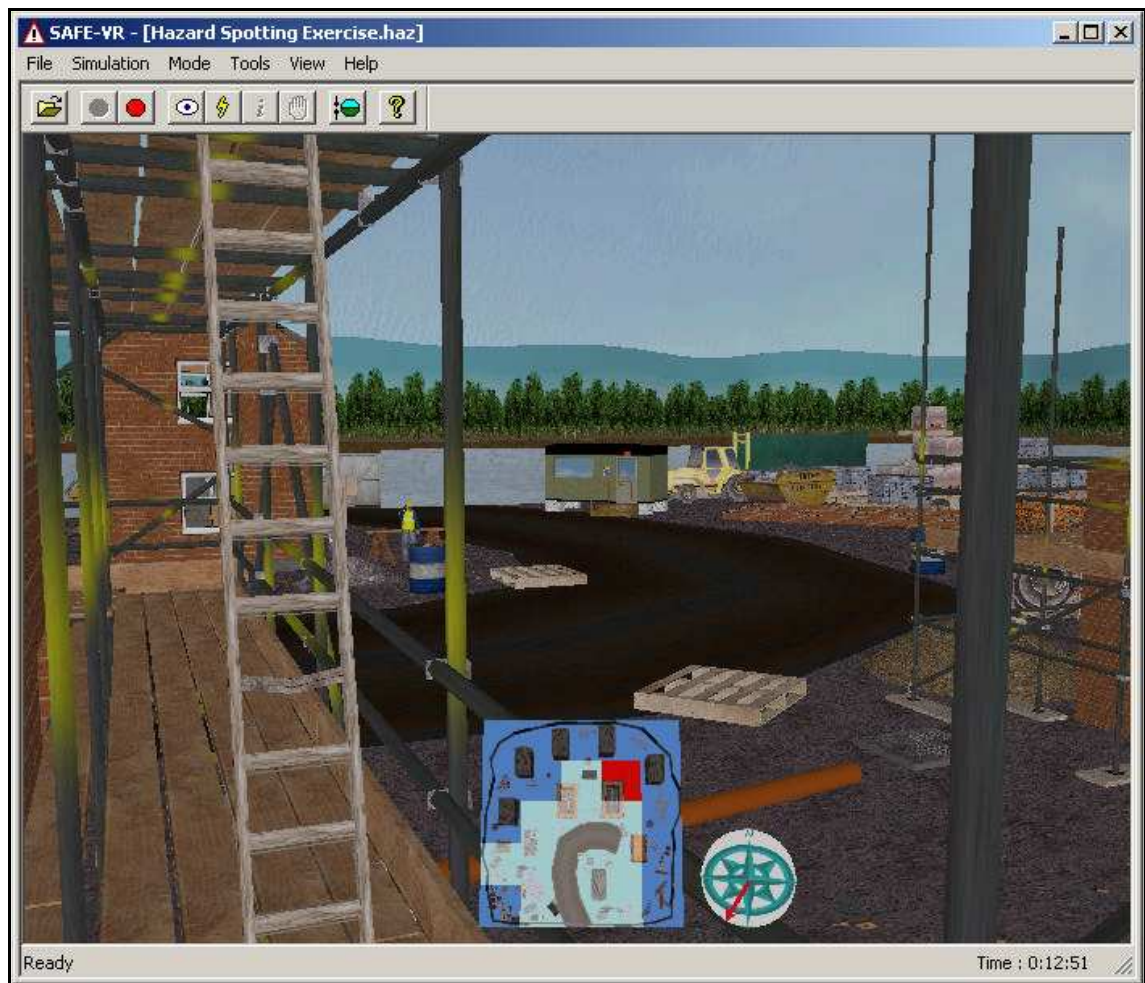


Figure A1.2: Screenshot from Safe-VR¹⁹¹.

The advantages of Safe-VR are explained in the AIMS Research internet web pages (AIMS Research, 2002):

“Virtual reality training systems are an indispensable addition to any training package. The use of high quality three-dimensional graphics, spatialised sound and dynamic simulation combine to form a uniquely engaging experience. New recruits can be trained on the latest equipment without ever taking your valuable resources out of production, and you can even try their nerve handling hazardous situations without actually putting them at risk. The computer-based nature of the training means that recruits can learn at their own rate, but the interactivity ensures their active participation, whilst the automatic scoring tracks their individual progress.”

¹⁹¹ Image and 3D model created by Burton (2002).

3D objects can be imported from various 3D CG software modelling packages such as 3D Studio MAX and sounds can be imported using the WAV file format. Objects and sounds can be associated with hazards which the user must then spot, identify and resolve correctly. This may involve interaction with objects such as valves, levers and other equipment controls. A detailed description of Safe-VR is given by Hollands *et al.* (1999).

For the research detailed in this thesis, Safe-VR has been used to develop a visual impact visualisation tool. The full simulation version of Safe-VR retails at approximately £6000, but has been freely available to use for the case studies in this thesis.

A1.6 Director 8.5 Shockwave Studio

Macromedia Director 8.5 Shockwave Studio is an authoring tool for creating interactive multimedia movies, presentations and VR simulations. Users can either view or download Director movies over the internet, or as a single or set of files suitable for distribution on CD-ROM and DVD-ROM. Glinert (2001) states:

“Director's movie-creation metaphor relies on a stage window where you arrange objects (called cast members) and orchestrate their ongoing behaviours via a timeline score. Cast members can be any type of media, such as bitmaps, text, video, Flash movies, and audio. At the basic level, you set the first frame where you want the cast member to appear in the score, make any changes in the object's "Mproperties" (position, colour, and so on), select the final frame, and play the animation. Director automatically generates the intermediate frames for you. You can use any of the included animation behaviours or design your own with the built-in scripting language called Lingo.”

Figure A1.3 shows a typical view of Director's user interface. The top left window is the stage, the top right window is the cast library and the bottom window is the timeline score. Director has been chosen due to its availability to the author and its versatility. The software currently

retails at approximately £1000.

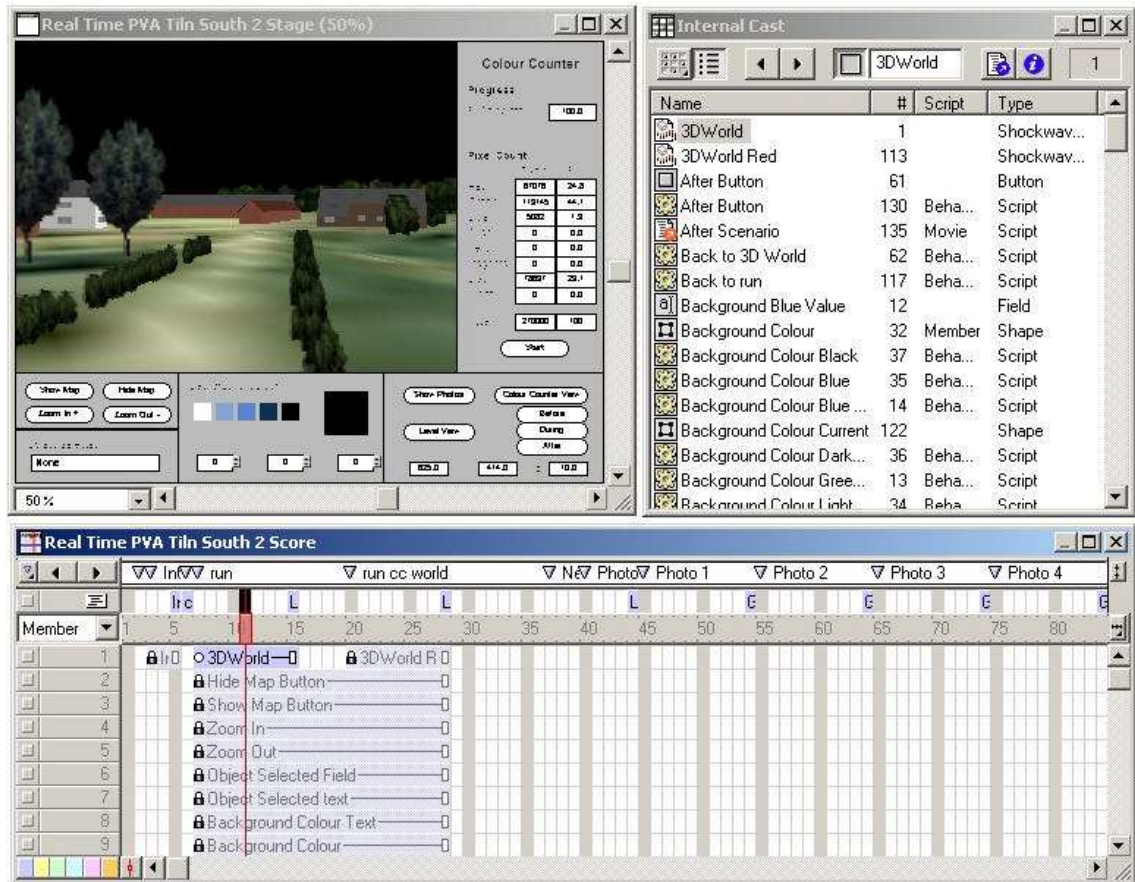


Figure A1.3: Director's user interface¹⁹².

A1.7 CorelDRAW

CorelDRAW 8, by Corel Corporation (2002), is an image editing software package and is able to manipulate both raster and vector images. CorelDRAW comes with many additional graphic utilities, one of which is called Corel OCR-TRACE. This utility converts raster images into vector images which can then be exported as "DXF" files. Corel OCR-TRACE has been used in this thesis to convert printed CAD data, such as contours, into a digital form which can then be subsequently opened in either AutoCAD or 3D Studio MAX. Figure A1.4 shows a screenshot of Corel OCR-TRACE with a raster image being converted into a vector image. CorelDRAW Graphics Suite 11 currently retails at approximately £300.

¹⁹² 3D model and Director screenshot by the author (January 2003).

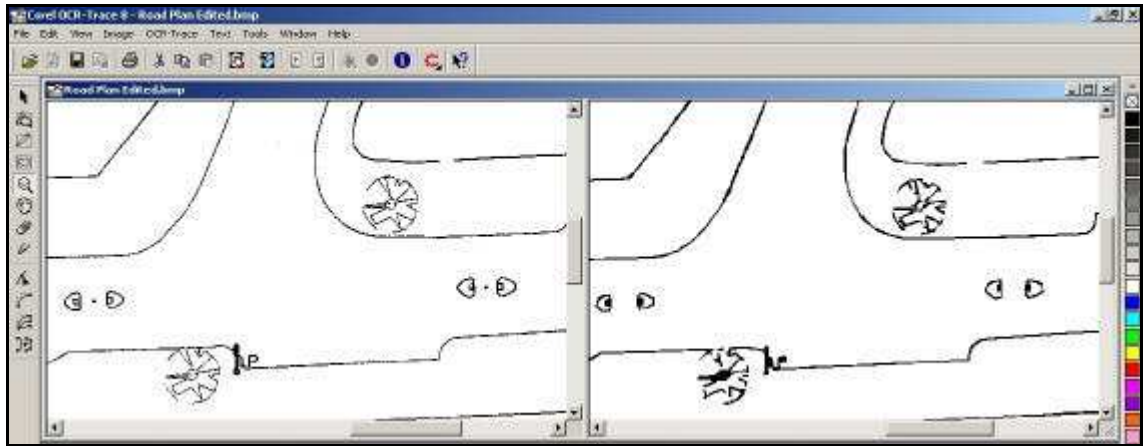


Figure A1.4: Screenshot of Corel OCR-TRACE¹⁹³

¹⁹³ Corel OCR-TRACE screenshot by the author (March 2003).

Appendix 2: Hardware Used

A2.1 Introduction

The purpose of this section is to establish the approximate current price and specification of a typical computer system that could run the software packages listed in appendix 3 which were required to develop the novel VIA techniques which are described in chapter 5.

A2.2 Required Hardware

Table A2.1 lists the fundamental hardware components of a typical minimum specification computer system showing the approximate price of each of the components. It is important to note that the component choices do not necessarily reflect the absolute minimum specification, but the minimum specification commercially available to buy brand new from July 2003. For example, an Intel Pentium III processor running at 500 MHz would be a suitable CPU but it is no longer produced and therefore has not been considered.

Component	Model	Price (£)
CPU	AMD Duron 1300 MHz	26
Memory	128 MB PC100 SDRAM	13
Hard Drive	30 GB 5400 RPM	44
Graphics	32 MB AGP	25
Sound	Stereo sound card and speakers	15
Monitor	17" CRT	90
Optical Drive	48 Speed CD-ROM	25
Input Devices	Keyboard and mouse	5
Other non-specifics	For example, motherboard, floppy drive, case	80
Construction		50
	Total	373

Table A2.1: Minimum hardware requirements.

It can be seen that the new VIA techniques do not require expensive hardware to operate and in fact most modern office or family based personal computers may conform to the minimum specification that has been chosen. It should also be noted however, that when the research detailed in this thesis started, the price of a minimum specification computer was much more expensive, retailing at approximately £800 in October 1999.

Appendix 3: Morpeth Flood Visualisation

A3.1 Introduction

A flood visualisation model of a town called Morpeth was developed for the Environment Agency in order for them to demonstrate, to the local residents and emergency planning personnel, the potential flooding problems that the town confronts. Morpeth is situated midway between Newcastle Upon Tyne and the Scottish Borders in the county of Northumbria and the cause of flooding for the town is the River Wansbeck, which passes through Morpeth (figure A3.1). The problem that the Environment Agency faced was that they were not able to illustrate the risk of flooding since there have been no recent floods to use as examples, therefore a 3D CG flood visualisation model was requested to effectively demonstrate the flooding risk.



Figure A3.1: The River Wansbeck flowing through Morpeth town centre¹⁹⁴.

The output from the flood visualisation model was presented in an interactive, browser based format. Appendix 4 contains a leaflet produced by AIMS Solutions which presents this case study.

¹⁹⁴ Image from Freefoto, Inc. (2002).

A3.2 Methodology

The work consisted of modelling part of Morpeth town centre including areas on both sides of the River Wansbeck. 3D Laser Mapping Ltd. used 3D laser scanning and digital photography to acquire the data needed for the 3D CG modelling. Using TerraScan (Terrasolid Ltd., 2002), a software package for processing laser scanning data, Dr. Graham Hunter, from 3D Laser Mapping Ltd., produced a point cloud data file which was then processed using AutoCAD Land Development Desktop (Autodesk, Inc., 2002e) by Mr. Jez Noond, from AIMS Research, to produce a triangulated wireframe mesh of the environment (figure A3.2).

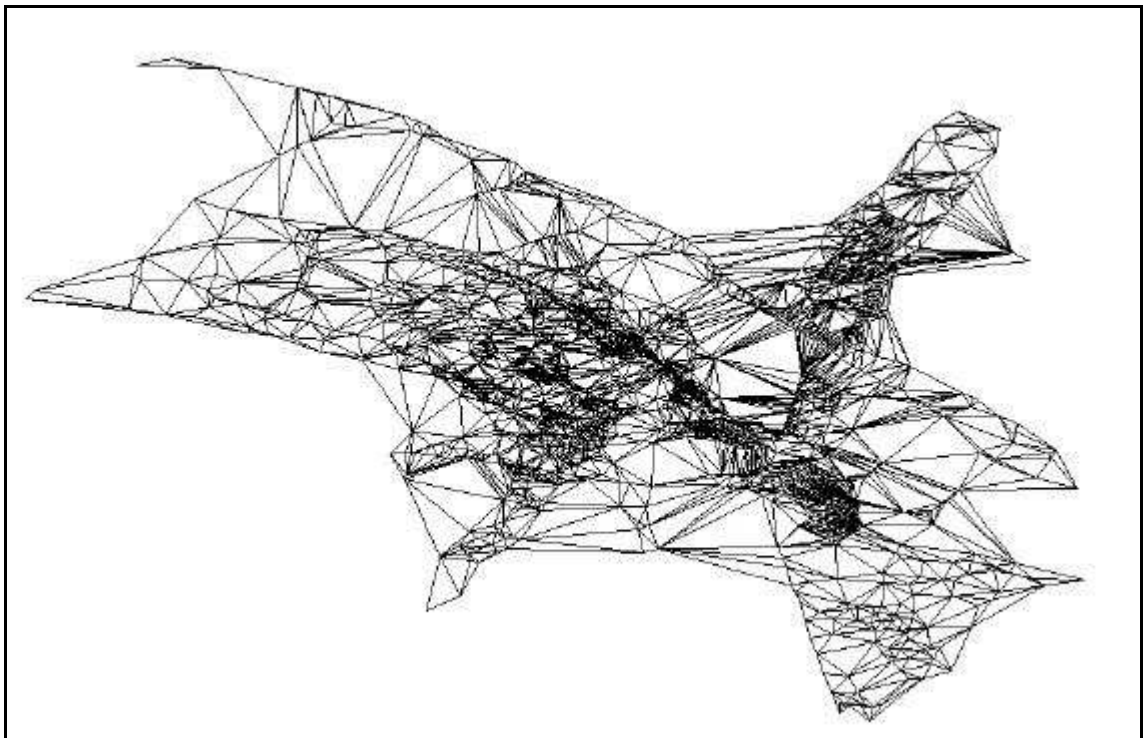


Figure A3.2: Wireframe mesh of Morpeth town centre¹⁹⁵.

Using the acquired data along with CAD plan data provided by the OS, the Morpeth model was produced using 3D Studio MAX 3.1 by the author, Dr. Damian Schofield and Mr. J. Noond for AIMS Research. Figure A3.3 shows a rendered image from the model, looking up the high street towards Oldgate Bridge which spans the River Wansbeck.

¹⁹⁵ 3D model created by Mr. J. Noond of AIMS Research (February 2002).



Figure A3.3: Rendered image from Morpeth 3D model¹⁹⁶.



Figure A3.4: Visualisation of Morpeth high street during a flood¹⁹⁷.

¹⁹⁶ and ⁴ Rendered images by author (February 2003) from a 3D model created by the author, Dr. D. Schofield and Mr. J. Noond for AIMS Solutions (2002).

Using data provided by the Environment Agency, the river water was animated to indicate rising water levels over time. Rendered stills and animations were produced from various key viewpoints for various water levels. Figure A3.4 shows the possible effect of the flood water at the one hundred year return level on Morpeth high street.

A3.3 Analysis

Using laser scanning techniques and digital photography it was possible to create an accurate model of part of Morpeth town centre in a relatively short time span of approximately three weeks. For a project of this nature it was essential that the model was precise, especially in terms of the landscape contours, so that the extent of the flooding could be accurately simulated. Using manual measuring techniques, such as levels and theodolites, would have been impractical due to the complexity of the model required and the short time span involved with the project.

The Environment Agency were pleased with the images and animations that were produced from the model and Environment Agency Manager Peter Kerr commented (Environment Agency, 2002):

“AIMS Solutions, from the University of Nottingham, were able to develop extremely realistic animations of the flooding in only a few weeks... ...We are delighted with the quality and realism of the work and have had a number of successful emergency planning meetings based on the scenarios presented.”

Appendix 4: AIMS Solutions Leaflets

Appendix 5: Bitmap Colour Counter MAXScript

```
utility colourcounter "Bitmap Colour Counter"
(
    group "About..."
    (
        label about_label01 "Bitmap Colour Counter"
        label about_label02 "by Chris Cox"
        label about_label03 "AIMS Research"
    )

    group "Settings:"
    (
        button get_image "Get Image File" width:140
        label bmpsize "Image Size:???x???"
        edittext bmp_name "File" text:""
        button view_image "View Image" width:140
        spinner framestep "Frame Step:" range:[1,10000,1] type:#integer
    )
    enabled:true

    group "Save Results:"
    (
        button save_as "Save As..." width:100 enabled:true
    )

    group "Progress:"
    (
        label percentlabel "% of Image Complete:"
        progressbar percent_complete align:#center
        label frame_num "Overall:??/"
        progressbar overall_complete align:#center
    )

    button start_process "Start Count" width:140 height:25 enabled:false

    on hellobut pressed do
    (
        for i = 1 to 1000 do
        (
            hello.value = 100*(i/1000)
        )
        hello.value=0
    )

    on save_as pressed do
    (
        file_name = getSaveFilename caption:"Save As..."
        types:"text(*.txt)|*.txt|"
        if file_name != undefined then f = createFile file_name
        if file_name != undefined then start_process.enabled = true
    )

    on get_image pressed do
```

```

(
    pick_image = selectBitmap caption:"Get Image File"
    if pick_image != undefined then bmp_name.text =
pick_image.filename

    try
    (
        work_bmp = openbitmap bmp_name.text
        bmp_w = work_bmp.width
        bmp_h = work_bmp.height
        bmpsize.text = "Image Size:" + bmp_w as string + "x" +
bmp_h as string
    )
    catch
    (
        messagebox "Image Is Not Valid!\nPlease Select A Valid
Image"
    ) -- end of catch
    )

on view_image pressed do
(
    try
    (
        work_bmp = openbitmap bmp_name.text
        display work_bmp
    )
    catch
    (
        messagebox "Image Is Not Valid!\nPlease Select A Valid
Image"
    ) -- end of catch
    )

on start_process pressed do
(
    try
    (
        fram = 0
        num = 0
        red_per = 0
        red = 0
        green_per = 0
        green = 0
        blue_per = 0
        blue = 0
        cyan_per = 0
        cyan = 0
        yellow_per = 0
        yellow = 0
        magenta_per = 0
        magenta = 0
        black_per = 0
        black = 0
        white_per = 0
        white = 0
        num = num as float
        fram = fram as integer
        red_per = red_per as float
        green_per = green_per as float
        blue_per = blue_per as float
        cyan_per = cyan_per as float
        yellow_per = yellow_per as float
    )
    )
)

```

```

magenta_per = magenta_per as float
black_per = black_per as float
white_per = white_per as float

total_pixels=bmp_w*bmp_h

format "\nBitmap Colour Counter   by Chris Cox\n\n" to:f
format "Image:  %\n" bmp_name.text to:f
format "Resolution:  % by %\n" bmp_w bmp_h to:f
format "Total Pixels:  %\n\n" total_pixels to:f
format "\n" to:f
format      "Frame,Red      Pixels,Percentage      Red,Green
Pixels,Percentage  Green,Blue  Pixels,Percentage  Blue,Cyan  Pixels,Percentage
Cyan,Yellow  Pixels,Percentage  Yellow,Magenta  Pixels,Percentage  Magenta,Black
Pixels,Percentage  Black,White  Pixels,Percentage  White\n" to:f
nth_frame = framestep.value

for t = 0 to (work_bmp.numframes-1) by nth_frame do
(
    fram=fram+1
    work_bmp.frame = t
    frame_num.text ="Overall:" + fram as string + "/" +
(work_bmp.numframes) as string

    for h = 1 to bmp_h do
    (
        pixel_line  = getpixels  work_bmp  [0,(h-1)]
bmp_w

        for w = 1 to bmp_w do
        (
            if  pixel_line[w].r  >=  128  and
pixel_line[w].g < 128 and pixel_line[w].b < 128 then red=red+1
            if  pixel_line[w].r  <  128  and
pixel_line[w].g >=128 and pixel_line[w].b < 128 then green=green+1
            if  pixel_line[w].r  <  128  and
pixel_line[w].g < 128 and pixel_line[w].b >=128 then blue=blue+1
            if  pixel_line[w].r  <  128  and
pixel_line[w].g >=128 and pixel_line[w].b >=128 then cyan=cyan+1
            if  pixel_line[w].r  >=128  and
pixel_line[w].g >=128 and pixel_line[w].b < 128 then yellow=yellow+1
            if  pixel_line[w].r  >=128  and
pixel_line[w].g < 128 and pixel_line[w].b >=128 then magenta=magenta+1
            if  pixel_line[w].r  <  128  and
pixel_line[w].g < 128 and pixel_line[w].b < 128 then black=black+1
            if  pixel_line[w].r  >=  128  and
pixel_line[w].g >= 128 and pixel_line[w].b >= 128 then white=white+1

            num = num + 1

        ) -- end of w loop

        per_comp = (100*(num/total_pixels as float))
as integer

        percent_complete.value = per_comp

    ) -- end of h loop

    per_comp=0
    overall_comp  =  (100*(fram/work_bmp.numframes  as
float)) as integer

    overall_complete.value = overall_comp

    red_per = (red *100/ total_pixels as float)
    green_per = (green *100/ total_pixels as float)
    blue_per = (blue *100/ total_pixels as float)
    cyan_per = (cyan *100/ total_pixels as float)
    yellow_per = (yellow *100/ total_pixels as float)

```

```

magenta_per = (magenta *100/ total_pixels as float)
black_per = (black *100/ total_pixels as float)
white_per = (white *100/ total_pixels as float)

format "%,%,%,%,%,%,%,%,%,%,%,%,%,%,%,%,%\n" t red
red_per green green_per blue blue_per cyan cyan_per yellow yellow_per magenta
magenta_per black black_per white white_per to:f

num=0
red_per = 0
red = 0
green_per = 0
green = 0
blue_per = 0
blue = 0
cyan_per = 0
cyan = 0
yellow_per = 0
yellow = 0
magenta_per = 0
magenta = 0
black_per = 0
black = 0
white_per = 0
white = 0
num = num as float
red_per = red_per as float
green_per = green_per as float
blue_per = blue_per as float
cyan_per = cyan_per as float
yellow_per = yellow_per as float
magenta_per = magenta_per as float
black_per = black_per as float
white_per = white_per as float

) -- end of t loop

close work_bmp
close f

) -- end of try

catch
(
messagebox "Image Is Not Valid!\nPlease Select A Valid
Image"
) -- end of catch

) -- end of on

) -- end of utility

```


Appendix 6: Earth Curver MAXScript

```
utility EarthCurver "Earth Curver"
(
    group "About..."
    (
        label about01 "Earth Curver"
        label about03 "by Chris Cox"
        label about04 "AIMS Research"
    )

    group "Options..."
    (
        label options01 "Please select units"
        dropdownlist units " "
        items:#("Millimeters","Centimeters","Meters","Kilometers","Inches","Feet","Miles") width:100 selection:3 align:#center
        label options02 "Please select closest altitude"
        dropdownlist alt " " items:#("0'","1000'","305m","10000'","3050m","15000'","4570m") width:120 selection:1
        align:#center
    )

    group "Selections..."
    (
        pickbutton choseit "Select Surface" width:100
        edittext surface fieldWidth:90 align:#center
        checkbox wherefrom "Origin as Reference" checked:true align:#left
        enabled:false
        pickbutton ref_pt "Reference Object" width:100 enabled:false
        edittext reference fieldWidth:90 align:#center enabled:false
    )

    group "Hold Scene..."
    (
        button holdit "Hold" width:100
    )

    group "Curve It..."
    (
        button curve "Curve" width:100 enabled:false
    )

    on holdit pressed do
    (
        max hold
    )

    on choseit picked obj do
    (
        master = obj
        surface.text = obj.name
        wherefrom.enabled=true
        curve.enabled=true
    )

    on wherefrom changed state do
    (
        if state == on do
        (
            ref_pt.enabled=false
            reference.enabled=false
            curve.enabled=true
        )
        if state == off do
        (
```

```

        ref_pt.enabled=true
        reference.enabled=true
        reference.text = ""
        curve.enabled=false
    )
)

on ref_pt picked objr do
(
    masterr = objr
    reference.text = objr.name
    curve.enabled=true
)

on curve pressed do
(
    addModifier choseit.object (normalModifier())
    collapseStack choseit.object
    sv = for i in choseit.object.verts collect i.index
    num_verts = sv.count
    if units.selection == 1 then f = 1e+012
    if units.selection == 1 then c = 1000
    if units.selection == 2 then f = 1e+010
    if units.selection == 2 then c = 100
    if units.selection == 3 then f = 1e+006
    if units.selection == 3 then c = 1
    if units.selection == 4 then f = 1
    if units.selection == 4 then c = 0.001
    if units.selection == 5 then f = 1.5500031e+009
    if units.selection == 5 then c = 39.37008
    if units.selection == 6 then f = 10.76391045e+006
    if units.selection == 6 then c = 3.28084
    if units.selection == 7 then f = 0.386104078
    if units.selection == 7 then c = 621.37119e-006
    if alt.selection == 1 then b = 0.574
    if alt.selection == 2 then b = 0.587
    if alt.selection == 3 then b = 0.597
    if alt.selection == 4 then b = 0.606

    for a = 1 to sv.count do
    (
        select choseit.object.verts[a]
        choseit.object.verts[#baz] = choseit.object.selectedVerts

        if wherefrom.checked then x =
(choseit.object.selectedVerts[1].pos.x) else x =
(choseit.object.selectedVerts[1].pos.x)-(ref_pt.object.pos.x)
        if wherefrom.checked then y =
(choseit.object.selectedVerts[1].pos.y) else y =
(choseit.object.selectedVerts[1].pos.y)-(ref_pt.object.pos.y)

        ds = (x^2) + (y^2)
        z = -0.117684518 * b * (ds/f) * c

        move choseit.object.verts[#baz] [0,0,z]
    )
    fileIn "c:\\3dsmax3_1\\scripts\\startup\\EarthCurver.ms"
)
)
)

```

Appendix 7: Birmingham University Hospital

A7.1 Visualisations Of The New University Hospital



Figure A7.1: Photomontage from critical viewpoint one showing the proposed hospital¹⁹⁸.

¹⁹⁸ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).



Figure A7.2: Photomontage from critical viewpoint two showing the proposed hospital¹⁹⁹.



Figure A7.3: Photomontage from critical viewpoint three showing the proposed hospital²⁰⁰.

¹⁹⁹ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).

²⁰⁰ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).



Figure A7.4: Photomontage from critical viewpoint four showing the proposed hospital²⁰¹.



Figure A7.5: Photomontage from critical viewpoint five showing the proposed hospital²⁰².

²⁰¹ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).

²⁰² Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).



Figure A7.6: Photomontage from critical viewpoint six showing the proposed hospital²⁰³.



Figure A7.7: Rendered image from critical viewpoint seven showing the proposed hospital²⁰⁴.

²⁰³ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).

²⁰⁴ Photomontage from a 3D model created by the author (May 2000) and a photograph by Babbie (2000c).

A7.2 Visualisations Of the Psychiatric Hospital



Figure A7.8: Rendered image from critical viewpoint one pre-development²⁰⁵.



Figure A7.9: Rendered image from critical viewpoint one post-development²⁰⁶.

²⁰⁵ Rendered image from a 3D model created by the author (May 2000).

²⁰⁶ Rendered image from a 3D model created by the author (May 2000).



Figure A7.10: Rendered image from critical viewpoint two pre-development²⁰⁷.



Figure A7.11: Rendered image from critical viewpoint two post-development²⁰⁸.

²⁰⁷ Rendered image from a 3D model created by the author (May 2000).

²⁰⁸ Rendered image from a 3D model created by the author (May 2000).



Figure A7.12: Rendered image from critical viewpoint three pre-development²⁰⁹.



Figure A7.13: Rendered image from critical viewpoint three post-development²¹⁰.

²⁰⁹ Rendered image from a 3D model created by the author (May 2000).

²¹⁰ Rendered image from a 3D model created by the author (May 2000).



Figure A7.14: Rendered image from critical viewpoint four pre-development²¹¹.



Figure A7.15: Rendered image from critical viewpoint four post-development²¹².

²¹¹ Rendered image from a 3D model created by the author (May 2000).

²¹² Rendered image from a 3D model created by the author (May 2000).



Figure A7.16: Rendered image from critical viewpoint five pre-development²¹³.



Figure A7.17: Rendered image from critical viewpoint five post-development²¹⁴.

²¹³ Rendered image from a 3D model created by the author (May 2000).

²¹⁴ Rendered image from a 3D model created by the author (May 2000).



Figure A7.18: Rendered image from critical viewpoint six pre-development²¹⁵.



Figure A7.19: Rendered image from critical viewpoint six post-development²¹⁶

²¹⁵ Rendered image from a 3D model created by the author (May 2000).

²¹⁶ Rendered image from a 3D model created by the author (May 2000).

Appendix 8: Bellmoor Quarry, Tiln South

A8.1 Rendered Images From Critical Viewpoints During The Summer



Figure A8.1: Pre-development view from critical viewpoint one²¹⁷.

²¹⁷ Images from a 3D model created by the author (June 2001).



Figure A8.2: View from critical viewpoint one during quarrying²¹⁸.



Figure A8.3: Post-development view from critical viewpoint one²¹⁹.

²¹⁸ Images from a 3D model created by the author (June 2001).

²¹⁹ Images from a 3D model created by the author (June 2001).



Figure A8.4: Pre-development view from critical viewpoint two²²⁰.



Figure A8.5: View from critical viewpoint two during quarrying²²¹.

²²⁰ Images from a 3D model created by the author (June 2001).

²²¹ Images from a 3D model created by the author (June 2001).



Figure A8.6: Post-development view from critical viewpoint two²²².



Figure A8.7: Pre-development view from critical viewpoint three²²³.

²²² Images from a 3D model created by the author (June 2001).

²²³ Images from a 3D model created by the author (June 2001).



Figure A8.8: View from critical viewpoint three during quarrying²²⁴.



Figure A8.9: Post-development view from critical viewpoint three²²⁵.

²²⁴ Images from a 3D model created by the author (June 2001).

²²⁵ Images from a 3D model created by the author (June 2001).



Figure A8.10: Pre-development view from critical viewpoint four²²⁶.



Figure A8.11: View from critical viewpoint four during quarrying²²⁷.

²²⁶ Images from a 3D model created by the author (June 2001).

²²⁷ Images from a 3D model created by the author (June 2001).



Figure A8.12: Post-development view from critical viewpoint four²²⁸.

²²⁸ Images from a 3D model created by the author (June 2001).

A8.2 Fields of Visual Influence



Figure A8.13: Pre-development reflective FVI from critical viewpoint one²²⁹.



Figure A8.14: Reflective FVI from critical viewpoint one during quarrying²³⁰.

²²⁹ Image by the author (June 2001).

²³⁰ Image by the author (June 2001).



Figure A8.15: Post-development reflective FVI from critical viewpoint one²³¹.



Figure A8.16: Pre-development reflective FVI from critical viewpoint two²³².

²³¹ Image by the author (June 2001).

²³² Image by the author (June 2001).



Figure A8.17: Reflective FVI from critical viewpoint two during quarrying²³³.



Figure A8.18: Post-development reflective FVI from critical viewpoint two²³⁴.

²³³ Image by the author (June 2001).

²³⁴ Image by the author (June 2001).



Figure A8.19: Pre-development reflective FVI from critical viewpoint three²³⁵.



Figure A8.20: Reflective FVI from critical viewpoint three during quarrying²³⁶.

²³⁵ Image by the author (June 2001).

²³⁶ Image by the author (June 2001).



Figure A8.21: Post-development reflective FVI from critical viewpoint three²³⁷.



Figure A8.22: Pre-development reflective FVI from critical viewpoint four²³⁸.

²³⁷ Image by the author (June 2001).

²³⁸ Image by the author (June 2001).



Figure A8.23: Reflective FVI from critical viewpoint four²³⁹.



Figure A8.24: Post-development reflective FVI from critical viewpoint four²⁴⁰.

²³⁹ Image by the author (June 2001).

²⁴⁰ Image by the author (June 2001).

A8.3 Rendered Images From Critical Viewpoints During The Winter



Figure A8.25: Pre-development view from critical viewpoint one²⁴¹.

²⁴¹ Images from a 3D model created by the author (June 2001).



Figure A8.26: View from critical viewpoint one during quarrying²⁴².



Figure A8.27: Post-development view from critical viewpoint one²⁴³.

²⁴² Images from a 3D model created by the author (June 2001).

²⁴³ Images from a 3D model created by the author (June 2001).



Figure A8.28: Pre-development view from critical viewpoint two²⁴⁴.



Figure A8.29: View from critical viewpoint two during quarrying²⁴⁵.

²⁴⁴ Images from a 3D model created by the author (June 2001).

²⁴⁵ Images from a 3D model created by the author (June 2001).



Figure A8.30: Post-development view from critical viewpoint two²⁴⁶.



Figure A8.31: Pre-development view from critical viewpoint three²⁴⁷.

²⁴⁶ Images from a 3D model created by the author (June 2001).

²⁴⁷ Images from a 3D model created by the author (June 2001).



Figure A8.32: View from critical viewpoint three during quarrying²⁴⁸.



Figure A8.33: Post-development view from critical viewpoint three²⁴⁹.

²⁴⁸ Images from a 3D model created by the author (June 2001).

²⁴⁹ Images from a 3D model created by the author (June 2001).



Figure A8.34: Pre-development view from critical viewpoint four²⁵⁰.



Figure A8.35: View from critical viewpoint four during quarrying²⁵¹.

²⁵⁰ Images from a 3D model created by the author (June 2001).

²⁵¹ Images from a 3D model created by the author (June 2001).



Figure A8.36: Post-development view from critical viewpoint four²⁵².

²⁵² Images from a 3D model created by the author (June 2001).

Appendix 9: CD-ROM