

# Contents

|   |    |
|---|----|
| Abstract.....   | IX |
| Chapter 1   |    |
| Introduction.....   | 1  |
| 1.1 3D GIS: problem areas .....                           | 3  |
| 1.2 Research scope .....                                  | 4  |
| 1.3 Previous work.....                                    | 5  |
| 1.4 Research objectives.....                              | 8  |
| 1.5 Organisation of the thesis .....                      | 9  |
| Chapter 2   |    |
| Fundamentals of 3D modelling and visualisation .....      | 11 |
| 2.1 Models and modelling .....                            | 11 |
| 2.1.1 Objects, attributes, relationships, operations..... | 12 |
| 2.1.2 Design phases in modelling .....                    | 13 |
| 2.1.3 Object-oriented principles .....                    | 14 |
| 2.1.4 Relational data model .....                         | 16 |
| 2.2 GIS models.....                                       | 17 |
| 2.2.1 Types of objects.....                               | 18 |
| 2.2.2 Attributes.....                                     | 18 |
| 2.2.3 Spatial relationships.....                          | 20 |
| 2.2.3.1 Set theory and topology.....                      | 20 |
| 2.2.3.2 Detection of spatial relationships.....           | 23 |
| 2.2.4 Operations .....                                    | 24 |
| 2.3 3D visualisation and interaction .....                | 26 |
| 2.3.1 Scene components.....                               | 27 |
| 2.3.1.1 Points and "empty" polygons.....                  | 28 |
| 2.3.1.2 "Filled" polygons.....                            | 28 |
| 2.3.2 Interaction and manipulation .....                  | 29 |
| 2.3.3 Levels of Detail.....                               | 31 |
| 2.4 The World Wide Web.....                               | 31 |
| 2.4.1 Techniques to access data on the Web.....           | 32 |
| 2.4.2 VRML: the Web standard for 3D visualisation.....    | 34 |
| 2.5 Summary.....  | 36 |
| Chapter 3   |    |
| Investigation of user requirements for 3D GIS .....       | 37 |
| 3.1 Methods of studying user requirements.....            | 38 |
| 3.2 Real objects of interest in urban areas .....         | 40 |
| 3.2.1 Inventory of real objects .....                     | 41 |
| 3.2.2 Geometric resolution.....                           | 45 |
| 3.2.3 Spatial relationships.....                          | 46 |
| 3.2.4 Realism.....  | 49 |

|   |  |     |
|---|--|-----|
| 3.3   | GUI, interaction and operations.....                                 | 50  |
| 3.4   | User requirements for a municipal 3D GIS.....                        | 52  |
| 3.5   | Summary.....   | 53  |
| Chapter 4                                   |  |     |
| Visualisation and interaction strategy..... |  | 55  |
| 4.1   | VRML concepts.....   | 55  |
| 4.1.1                                       | Visualisation of urban models in VRML.....                           | 56  |
| 4.1.2                                       | Approaches to design VRML worlds.....                                | 61  |
| 4.2   | System architecture for a Web 3D GIS.....                            | 62  |
| 4.2.1                                       | Query, visualisation, modification.....                              | 63  |
| 4.2.2                                       | Creation of VRML documents on the fly.....                           | 66  |
| 4.3   | Visualisation requirements.....                                      | 68  |
| 4.4   | Summary.....   | 69  |
| Chapter 5                                   |  |     |
| Conceptual design.....                      |  | 71  |
| 5.1   | Summarised requirements for 3D GIS on the Web.....                   | 71  |
| 5.2   | Framework for object identification and information structuring..... | 73  |
| 5.2.1                                       | Objects: spatial and non-spatial.....                                | 73  |
| 5.2.2                                       | Object components in the geometric domain.....                       | 76  |
| 5.2.2.1                                     | Geometric appearance (GA).....                                       | 76  |
| 5.2.2.2                                     | Geometric relationships (GR).....                                    | 77  |
| 5.2.2.3                                     | Geometric behaviour (GB).....  | 78  |
| 5.2.3                                       | Composite objects.....   | 80  |
| 5.3   | Spatial models.....  | 82  |
| 5.3.1                                       | 3D FDS.....  | 83  |
| 5.3.2                                       | TEN.....   | 86  |
| 5.3.3                                       | The cell tuple model.....  | 89  |
| 5.4   | Arcs in spatial models.....  | 91  |
| 5.5   | The Simplified Spatial Model (SSM).....                              | 93  |
| 5.5.1                                       | Definition of constructive objects.....                              | 93  |
| 5.5.2                                       | Definition of geometric objects.....                                 | 97  |
| 5.6   | SSM for urban modelling.....   | 106 |
| 5.7   | Summary.....   | 107 |
| Chapter 6                                   |  |     |
| 3D topological relations and SSM.....       |  | 109 |
| 6.1   | Topological relations between two simple geometric objects.....      | 109 |
| 6.1.1                                       | Negative conditions.....   | 112 |
| 6.1.2                                       | Possible relations.....  | 120 |
| 6.1.3                                       | Completeness of the obtained relations.....                          | 126 |
| 6.1.4                                       | Topological equivalent spatial relationships.....                    | 130 |
| 6.2   | Topological relations supported by SSM.....                          | 133 |
| 6.2.1                                       | Point relations.....   | 134 |
| 6.2.2                                       | Line relations.....  | 135 |
| 6.2.3                                       | Surface relations.....   | 140 |

|   |  |     |
|---|--|-----|
| 6.2.4   | Body relations.....  | 144 |
| 6.3   | Usefulness of the decimal codes.....                               | 146 |
| 6.4   | SSM for spatial analysis in urban areas.....                       | 147 |
| 6.5   | Summary.....   | 148 |
| Chapter 7   |  |     |
| Logical design and data collection .....  |  | 151 |
| 7.1   | 3D R-tree for LOD and spatial indexing .....                       | 151 |
| 7.2   | Simplified Spatial Schema (SSS).....                               | 154 |
| 7.3   | SSS and procedures for data collection .....                       | 159 |
| 7.3.1   | GDsc: procedures for semi-automatic 3D object reconstruction ..... | 160 |
| 7.3.2   | GDsc: 3D reconstruction from existing data.....                    | 164 |
| 7.3.3   | GAtt: texture and texturing.....                                   | 166 |
| 7.3.3.1   | Texture mapping: buildings .....                                   | 168 |
| 7.3.3.2   | Texture draping: terrain .....                                     | 170 |
| 7.4   | Summary.....   | 171 |
| Chapter 8   |  |     |
| Implementation: prototype system, case studies.....   |  | 173 |
| 8.1   | Prototype system.....  | 173 |
| 8.2   | Case study 1: GUI for query and visualisation.....                 | 176 |
| 8.2.1   | Data query .....   | 176 |
| 8.2.2   | Data visualisation .....   | 181 |
| 8.2.3   | Data modification .....  | 182 |
| 8.2.4   | Data exploration and manipulation .....                            | 184 |
| 8.3   | Case study 2: Dynamic creation of LOD .....                        | 185 |
| 8.3.1   | 3D R-tree creation.....  | 185 |
| 8.3.2   | Organisation of LOD .....  | 189 |
| 8.3.3   | Dynamic creation of LOD .....                                      | 190 |
| 8.4   | Case study 3: Performance.....                                     | 190 |
| 8.4.1   | Size performance .....   | 191 |
| 8.4.2   | Time performance.....  | 196 |
| 8.5   | Summary.....   | 201 |
| Chapter 9   |  |     |
| Conclusions and further research .....  |  | 203 |
| 9.1   | Summary.....   | 203 |
| 9.2   | Outcomes .....   | 207 |
| 9.3   | Conclusions.....   | 209 |
| 9.4   | Further research .....   | 210 |
| References .....  |  | 213 |
| Appendix 1: Questionnaire for investigation of user requirements for 3D GIS among 15 producers of GIS and 3D CAD urban data ..... |  | a   |
| Appendix 2: An approach to display ID of objects in VR browsers.....  |  | e   |
| Appendix 3: 3D topological relations.....   |  | i   |
| Appendix 4: Guiding animation.....  |  | o   |
| Abstracts in German and Bulgarian.....  |  | q   |

