

## Appendix 1: Questionnaire for investigation of user requirements for 3D GIS among 15 producers of GIS and 3D CAD urban data

**Table 1: Current status: 2D, 2.5D, 3D**

|                      | 1         | 2         | 3         | 4         | 5         | 6         | 7   | 8         | 9         | 10        | 11        | 12        | 13        | 14        | 15 |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----|
| Orientation          | 2         | 2         | 2         | 2         | 2         | 2         | 2   | 2         | 2         | 2         | 2,3       | 2         | 2,3       | 1,2       | 3  |
| Stored data          | 1,2<br>,3 | 1,2<br>,3 | 1,2       | 1,2       | 1,2       | 1,2<br>,3 | 1   | 1,2<br>,3 | 2         | 1,2       | 2         | 2         | 1,2       | 1,2       | 1  |
| Used data            | 1,2<br>,3 | 1,2<br>,3 | 1,2       | 1,2       | 1,2       | 1,2<br>,3 | 1   | 1,2<br>,3 | 1,2       | 1,2       | 1         | 1         | 1,2       | 1,2       | 1  |
| Output               | 1,2<br>,3 | 1,2<br>,3 | 1,2       | 1         | 1         | 1,2<br>,3 | 1   | 1,2<br>,3 | 1         | 1         | 2         | 2         | 1         | 1         | 1  |
| Data type            | 1,2<br>,3 | 1,2<br>,3 | 1,2<br>,3 | 1,2<br>,3 | 1,2<br>,3 | 1         | 1,2 | 1,2       | 1,2<br>,3 | 1,2,<br>3 | 1,2,<br>3 | 1,2,<br>3 | 1,2,<br>3 | 1,2,<br>3 | 1  |
| Software:<br>storage | 1,2<br>,3 | 1         | 1,2<br>,3 | 1         | 1,2       | 2         | 1,2 | 1,3       | 1,2       | 1,2       | 1,2       | 1,2       | 1,2       | 1,2       | 2  |
| Software:<br>display | 1,2       | 1,4       | 1,2<br>,4 | 1         | 2         | 2,4       | 1,2 | 1         | 1,2       | 1,2       | 1         | 1,4       | 2,4       | 1,4       | 2  |

Orientation: 1-Urban areas, 2-combined (urban + something else), 3-others

Geometry: stored, used data, output: 1-2D, 2-2.5D, 3-3D

Data type: 1-geometry, 2-attributes, 3-relationships

Software for data storage: 1-GIS, 2-CAD, 3-DBMS, 4-VR

**Table 2: Analysis in 2D and 2.5D**

|               | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| Metric        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | ✓  |
| Positional    | ✓ | - | ✓ | - | ✓ | - | - | ✓ | ✓ | ✓  | ✓  | -  | ✓  | -  | -  |
| Network       | ✓ | - | ✓ | - | ✓ | - | - | ✓ | - | -  | -  | ✓  | -  | -  | -  |
| Analysis      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |
| Proximity     | ✓ | ✓ | ✓ | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓  | ✓  | -  | -  | -  | -  |
| Relationships | ✓ | ✓ | ✓ | - | ✓ | - | - | - | ✓ | ✓  | -  | -  | -  | -  | -  |
| Analysis      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |
| Visibility    | ✓ | - | - | - | - | ✓ | - | ✓ | - | -  | ✓  | ✓  | -  | -  | -  |
| Semantic      | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | ✓  |
| Mixed         | ✓ | ✓ | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |

✓ yes, -no

**Table 3: Objects of interest: 2D, 2.5D**

|                    | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|--------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| Buildings          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Other              | ✓ | - | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | -  | ✓  | ✓  |
| Constructions      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |
| Streets            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | -  |
| Paths              | - | ✓ | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | -  |
| Parks              | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | -  |
| Utilities          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | -  | ✓  | -  |
| Telecommunications | ✓ | ✓ | - | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | -  | ✓  | -  |
| Vegetation         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |

✓ yes, -no

**Table 4: Resolution: 2D**

|                               | 1     | 2   | 3   | 4     | 5     | 6 | 7         | 8 | 9   | 10  | 11 | 12 | 13 | 14 | 15 |
|-------------------------------|-------|-----|-----|-------|-------|---|-----------|---|-----|-----|----|----|----|----|----|
| Buildings                     | 1,6,7 | 1,9 | 1,5 | 1,5   | 1     | r | 1,2,5,6,8 | 1 | 1,5 | 1,5 | 1  | 1  | 1  | 1  | 1  |
| Streets                       | 1,2   | 1,2 | 1,2 | 1,2,3 | 1,2,3 | 1 | 1,2,3     | 2 | 2   | 2   | 2  | 2  | 2  | 2  | 2  |
| Paths (min width)             | 0.2   | in  | r   | In    | -     | r | -         | - | -   | R   | r  | in | r  | In | -  |
| Parks (min area)              | 0.6   | in  | 0.5 | In    | 0,5   | r | -         | - | -   | R   | r  | in | r  | In | -  |
| Utilities (min area)          | 0.6   | in  | r   | In    | in    | r | -         | - | -   | R   | r  | in | r  | In | -  |
| Telecommunications (min area) | 0.6   | -   | -   | -     | -     | r | -         | - | -   | -   | -  | in | -  | In | -  |

Buildings: 1-footprints, 2-roofs, 3-roof facets, 4-chimneys, 5-floors, 6-rooms, 7-room elements, 8-facades, 9-height

Streets: 1-pedestrian areas, 2-car tracks, 3-gardens

r – on request; in – instructions

**Table 5: Visualisation: 3D preferences**

|                               | 1     | 2     | 3     | 4   | 5 | 6     | 7   | 8     | 9 | 10 | 11    | 12  | 13    | 14 | 15 |
|-------------------------------|-------|-------|-------|-----|---|-------|-----|-------|---|----|-------|-----|-------|----|----|
| Dimensions                    | 3     | 1     | 1     | 3   | 3 | 3     | 3   | 1,2,3 | 3 | 3  | 1,2,3 | 2   | 1     | 1  | 1  |
| Screens                       | ✓     | ✓     | ✓     | -   | ✓ | ✓     | ✓   | ✓     | ✓ | ✓  | ✓     | ✓   | ✓     | ✓  | ✓  |
| Methods                       | 1,3   | 1     | 1,2,3 | 1,2 | 1 | 1,2,3 | 1,3 | 1,2   | 1 | 1  | 1     | 1,2 | 1,2   | 1  | 1  |
| Photo texture                 | ✓     | ✓     | -     | -   | ✓ | ✓     | ✓   | ✓     | ✓ | ✓  | ✓     | ✓   | ✓     | ✓  | ✓  |
| Texture instead of geometry   | ✓     | ✓     | -     | -   | ✓ | ✓     | -   | ✓     | ✓ | ✓  | -     | -   | ✓     | ✓  | ✓  |
| Sources                       | 1,2,3 | 1,2,3 | -     | -   | 2 | 1,2,3 | 1,3 | 1,2,3 | 1 | 1  | 1,2   | 1   | 1,2,3 | 1  | 1  |
| Software Different resolution | 1     | 2,3   | 4     | 5   | 1 | 1,5   | -   | 1,5   | 1 | 1  | -     | 1,5 | 1     | 1  | -  |

Preferable dimensions: 1-2D, 2-3D, 3-both

Screen spiting with several views: ✓ yes, -no

Methods for geometry display: 1-frame, 2-shading, 3-photo texture

Utilisation of photo texture: ✓ yes, -no

Available source images for photo textures : 1-aerial, 2-terrestrial, 3-conventional camera

Known software for texture mapping: 1-3D Studio, 2-VRML, 3-OpenGL, 4-ArcView, 5-Others

Possibility to visualise geometry with texture: ✓ yes, -no

Necessity of different resolution: ✓ yes, -no

**Table 6: Interaction: 2D, 2.5D**

|                        | 1     | 2     | 3     | 4     | 5     | 6   | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15  |
|------------------------|-------|-------|-------|-------|-------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| Elements               | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 3,4 | 1,2,4 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2,3 | 1,2 |
| Updating               | 1,2   | 1,2,3 | 1     | 2,3   | 1     | 3   | 2,3   | 1,2   | 2,3   | 2     | 2     | 2     | 2,3   | 1,2   | 2,3 |
| Means for manipulation | 1,2   | 1,2   | 1     | 1     | 1     | 1   | 1,2   | 1     | 1     | 1     | 1,2   | 1     | 1,2   | 1,2   | 1   |
| Preferable environment | 1     | 1     | 1     | 1     | 1     | 1,2 | 1     | 1     | 1     | 1     | 1,3   | 1     | 2,3   | 1     | 1   |

Mostly manipulated elements: 1-points, 2-lines, 3-faces, 4-bodies

Current manner of updating: 1-automatic, 2-semiautomatic, 3-manual

b

Means for manipulation: 1-mouse, 2-keyboard, 3-other (what)

Preferable visualisation methods for manipulation: 1-wire frame, 2-shaded, 3-textured

**Table 7: Symbolisation: 3D**

|                           | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| Geometric domain          | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Thematic domain           | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | ✓  |
| Geodetic network          | ✓ | ✓ | - | r | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | ✓  |
| Utilities                 | ✓ | ✓ | - | r | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | -  | ✓  | ✓  | ✓  |
| Transport network         | ✓ | ✓ | - | r | ✓ | ✓ | - | ✓ | ✓ | ✓  | -  | -  | ✓  | ✓  | ✓  |
| Information signs         | ✓ | ✓ | - | r | ✓ | ✓ | - | ✓ | ✓ | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Signs on public buildings | ✓ | ✓ | - | r | ✓ | ✓ | - | ✓ | ✓ | ✓  | -  | ✓  | ✓  | ✓  | ✓  |
| Others                    | i | - | - | r | ✓ | ✓ | - | ✓ | ✓ | ✓  | -  | ✓  | ✓  | r  | ✓  |

✓ yes, - no, r- on request, i -instructions

d

## Appendix 2: An approach to display ID of objects in VR browsers

1. An TOUCH PROTO node to visualise ID's of objects on a billboard. The ID is visualised when the cursor is on an object. Two boxes on the snapshot are meant for objects. The TOUCH node changes the image with the ID of the shape according to the ID of the object.

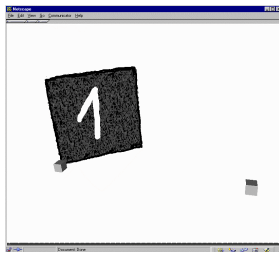


Figure 1: A snapshot of the PROTO TOUCH node in action

```
#VRML V2.0 utf8
#98-99
#S.Zlatanova
#identification of objects

PROTO TOUCH [
  field      SFInt32      nodeID 0
  eventOut   MFString    string_changed
]
{
  DEF SENS TouchSensor {}
  #Script
  DEF NODE Script {
    url "javascript:
      function set_boolean (bool)
      {
        if ((bool == true)&&(nodeID == 1))
          string_changed [0] = '1.jpg';

        if ((bool == true)&&(nodeID == 2))
          string_changed [0] = '2.jpg';

        if ((bool == false)|| (nodeID == 0))
          string_changed [0] = 'x.jpg';

      }
    "
    eventIn SFBool set_boolean
    eventOut MFString string_changed IS string_changed
    field SFInt32 nodeID IS nodeID
  }
  ROUTE SENS.isOver TO NODE.set_boolean
}
```

```

}#TOUCH

Group {
  children [
    DEF Box1 TOUCH {
      nodeID 1
    }
  ]
  Shape {
    appearance Appearance {
      material Material {}
    }
    geometry Box {
      size 0.1, 0.1, 0.1
    }
  }
]

Transform {
  translation 2 0 0
  children [
    DEF Box2 TOUCH {
      nodeID 2
    }
  ]
  Shape {
    appearance Appearance {
      material Material {}
    }
    geometry Box {
      size 0.1, 0.1, 0.1
    }
  }
]

Billboard {
  children[
    Shape {
      appearance Appearance {
        material Material {}
        texture DEF TEXT ImageTexture {}
      }
      geometry IndexedFaceSet {
        coord Coordinate {
          point[
            0 0 0,
            1 0 0,
            1 1 0,
            0 1 0,
          ]
        }
        coordIndex [0,1,2,3,]
      }
    }
  ]
  axisOfRotation 0.0 1.0 0.0
}

#changing texture
ROUTE Box1.string_changed TO TEXT.set_url

```

f

```
ROUTE Box2.string_changed TO TEXT.set_url
```

**2. Display of ID's without the designed PROTO node (text shapes are used instead of billboards).** The corresponding lines needed for the same operation are given in a bolt font in both variants.

```
#VRML V2.0 utf8
#98-99
#S. Zlatanova
#identification of objects
Group{
  children[
    Transform {
      children[
DEF Box1 TouchSensor {}
        Shape {
          appearance Appearance {
            material Material {}
          }
          geometry Box {
            size 0.1, 0.1, 0.1}
        }
      ]}

    Transform {
      translation 3 0 0
      children[
DEF Box2 TouchSensor {}
        Shape {
          appearance Appearance {
            material Material {
              diffuseColor 0.60 0.20 0.30
            }
          }
          geometry Box {
            size 0.1, 0.1, 0.1}
        }
      ]}

    Shape {
      appearance Appearance {
        material Material {}
      }
      geometry DEF TEXT Text {
        length [1,6]}
    }
  #Script
  DEF Node1 Script {
    url "javascript:
      function set_boolean (bool)
      {
        if (bool == true)
          string_changed [0] = '21';
        if (bool == false)
          string_changed [0] = ' ';
      }
    "

```

```

    eventIn SFBool set_boolean
    eventOut MFString string_changed
}
DEF Node2 Script {
    url "javascript:
        function set_boolean (bool)
        {
            if (bool == true)
                string_changed [0] = '22';
            if (bool == false)
                string_changed [0] = ' ';
        }

    "
    eventIn SFBool set_boolean
    eventOut MFString string_changed
}

]
}
#changing text
ROUTE Box1.isOver TO Node1.set_boolean
ROUTE Node1.string_changed TO TEXT.set_string
ROUTE Box2.isOver TO Node2.set_boolean
ROUTE Node2.string_changed TO TEXT.set_string

```

h

### Appendix 3: 3D topological relations

**Table 1: Groups of relations, names, closure intersection and exterior intersections**

| Group | Name     | Closure intersections        |                        |                           |                  |                    | Exterior intersections |                    |                       |                    |      |
|-------|----------|------------------------------|------------------------|---------------------------|------------------|--------------------|------------------------|--------------------|-----------------------|--------------------|------|
|       |          | $\partial A \cap \partial B$ | $A^\circ \cap B^\circ$ | $\partial A \cap B^\circ$ | $A^\circ \cap B$ | $A^\circ \cap B^-$ | $A^- \cap \partial B$  | $A^- \cap B^\circ$ | $\partial A \cap B^-$ | $A^\circ \cap B^-$ |      |
| 1     | Disjoint | R026                         | 0                      | 0                         | 0                | 0                  | 1                      | 0                  | 1                     | 0                  | R026 |
|       |          | R027                         | 0                      | 0                         | 0                | 0                  | 1                      | 0                  | 1                     | 1                  | R027 |
|       |          | R030                         | 0                      | 0                         | 0                | 0                  | 1                      | 1                  | 1                     | 0                  | R030 |
|       |          | R031                         | 0                      | 0                         | 0                | 0                  | 1                      | 1                  | 1                     | 1                  | R031 |
|       |          | R051                         | 0                      | 0                         | 0                | 1                  | 1                      | 0                  | 1                     | 1                  | R051 |
| 2     |          | R055                         | 0                      | 0                         | 0                | 1                  | 1                      | 1                  | 1                     | 1                  | R055 |
|       |          | R063                         | 0                      | 0                         | 0                | 1                  | 1                      | 1                  | 1                     | 1                  | R063 |
|       |          | R092                         | 0                      | 0                         | 1                | 1                  | 1                      | 1                  | 0                     | 0                  | R092 |
| 3     |          | R093                         | 0                      | 0                         | 1                | 1                  | 1                      | 1                  | 0                     | 1                  | R093 |
|       |          | R095                         | 0                      | 0                         | 1                | 1                  | 1                      | 1                  | 1                     | 1                  | R095 |
|       |          | R117                         | 0                      | 0                         | 1                | 1                  | 1                      | 0                  | 1                     | 1                  | R117 |
|       |          | R119                         | 0                      | 0                         | 1                | 1                  | 1                      | 0                  | 1                     | 1                  | R119 |
| 4     |          | R125                         | 0                      | 0                         | 1                | 1                  | 1                      | 1                  | 1                     | 1                  | R125 |
|       |          | R127                         | 0                      | 0                         | 1                | 1                  | 1                      | 1                  | 1                     | 1                  | R127 |
|       |          | R159                         | 0                      | 1                         | 0                | 1                  | 1                      | 1                  | 1                     | 1                  | R159 |
|       |          | R179                         | 0                      | 1                         | 0                | 1                  | 1                      | 0                  | 1                     | 1                  | R179 |
| 6     | Contain  | R183                         | 0                      | 1                         | 0                | 1                  | 1                      | 0                  | 1                     | 1                  | R183 |
|       |          | R191                         | 0                      | 1                         | 0                | 1                  | 1                      | 1                  | 1                     | 1                  | R191 |
|       |          | R220                         | 0                      | 1                         | 1                | 0                  | 1                      | 1                  | 0                     | 0                  | R220 |
| 7     | Inside   | R221                         | 0                      | 1                         | 1                | 0                  | 1                      | 1                  | 1                     | 0                  | R221 |
|       |          | R223                         | 0                      | 1                         | 1                | 0                  | 1                      | 1                  | 1                     | 1                  | R223 |
|       |          | R243                         | 0                      | 1                         | 1                | 1                  | 1                      | 0                  | 1                     | 1                  | R243 |
|       |          | R245                         | 0                      | 1                         | 1                | 1                  | 1                      | 0                  | 0                     | 1                  | R245 |
|       |          | R247                         | 0                      | 1                         | 1                | 1                  | 1                      | 0                  | 1                     | 1                  | R247 |
| 8     | Overlap  | R252                         | 0                      | 1                         | 1                | 1                  | 1                      | 1                  | 0                     | 0                  | R252 |
|       |          | R253                         | 0                      | 1                         | 1                | 1                  | 1                      | 1                  | 0                     | 1                  | R253 |
|       |          | R255                         | 0                      | 1                         | 1                | 1                  | 1                      | 1                  | 1                     | 1                  | R255 |
|       |          |                              |                        |                           |                  |                    |                        |                    |                       |                    |      |
|       |          |                              |                        |                           |                  |                    |                        |                    |                       |                    |      |

**Table 1: Groups of relations, names, closure intersection and exterior intersections (continue)**

| Group | Name   | Closure intersections        |                        |                           |                           | Exterior intersections |                       |                    |                       |   |      |      |
|-------|--------|------------------------------|------------------------|---------------------------|---------------------------|------------------------|-----------------------|--------------------|-----------------------|---|------|------|
|       |        | $\partial A \cap \partial B$ | $A^\circ \cap B^\circ$ | $\partial A \cap B^\circ$ | $A^\circ \cap \partial B$ | $A^- \cap B^-$         | $A^- \cap \partial B$ | $A^\circ \cap B^-$ | $\partial A \cap B^-$ |   |      |      |
| 9     | Meet   | R272                         | 1                      | 0                         | 0                         | 0                      | 1                     | 0                  | 0                     | 0 | 0    | R272 |
|       |        | R275                         | 1                      | 0                         | 0                         | 0                      | 1                     | 0                  | 0                     | 1 | 1    | R275 |
|       |        | R277                         | 1                      | 0                         | 0                         | 0                      | 1                     | 0                  | 1                     | 0 | 0    | R277 |
|       |        | R279                         | 1                      | 0                         | 0                         | 0                      | 1                     | 0                  | 1                     | 1 | 1    | R279 |
|       |        | R284                         | 1                      | 0                         | 0                         | 0                      | 1                     | 1                  | 1                     | 0 | 0    | R284 |
|       |        | R285                         | 1                      | 0                         | 0                         | 0                      | 1                     | 1                  | 1                     | 0 | 1    | R285 |
|       |        | R287                         | 1                      | 0                         | 0                         | 0                      | 1                     | 1                  | 1                     | 1 | 1    | R287 |
|       |        | R311                         | 1                      | 0                         | 0                         | 1                      | 1                     | 1                  | 1                     | 1 | 1    | R311 |
| 10    |        | R316                         | 1                      | 0                         | 0                         | 1                      | 1                     | 1                  | 0                     | 0 | R316 |      |
|       |        | R317                         | 1                      | 0                         | 0                         | 1                      | 1                     | 1                  | 1                     | 1 | R317 |      |
|       |        | R319                         | 1                      | 0                         | 0                         | 1                      | 1                     | 1                  | 1                     | 1 | R319 |      |
|       |        | R339                         | 1                      | 0                         | 1                         | 0                      | 1                     | 0                  | 0                     | 1 | 1    | R339 |
| 11    |        | R343                         | 1                      | 0                         | 1                         | 0                      | 1                     | 0                  | 1                     | 1 | R343 |      |
|       |        | R349                         | 1                      | 0                         | 1                         | 0                      | 1                     | 1                  | 1                     | 0 | 1    | R349 |
|       |        | R351                         | 1                      | 0                         | 1                         | 0                      | 1                     | 1                  | 1                     | 1 | 1    | R351 |
|       |        | R373                         | 1                      | 0                         | 1                         | 1                      | 1                     | 0                  | 1                     | 0 | 1    | R373 |
|       |        | R375                         | 1                      | 0                         | 1                         | 1                      | 1                     | 0                  | 1                     | 1 | 1    | R375 |
|       |        | R381                         | 1                      | 0                         | 1                         | 1                      | 1                     | 1                  | 1                     | 0 | 1    | R381 |
|       |        | R383                         | 1                      | 0                         | 1                         | 1                      | 1                     | 1                  | 1                     | 1 | 1    | R383 |
| 13    | Equal  | R400                         | 1                      | 1                         | 0                         | 0                      | 1                     | 0                  | 0                     | 0 | 0    | R400 |
|       |        | R403                         | 1                      | 1                         | 0                         | 0                      | 1                     | 0                  | 0                     | 1 | 1    | R403 |
|       |        | R405                         | 1                      | 1                         | 0                         | 0                      | 1                     | 0                  | 1                     | 0 | 1    | R405 |
|       |        | R407                         | 1                      | 1                         | 0                         | 0                      | 1                     | 0                  | 1                     | 1 | 1    | R407 |
|       |        | R412                         | 1                      | 1                         | 0                         | 0                      | 1                     | 1                  | 1                     | 0 | 0    | R412 |
|       |        | R413                         | 1                      | 1                         | 0                         | 0                      | 1                     | 1                  | 1                     | 0 | 1    | R413 |
|       |        | R415                         | 1                      | 1                         | 0                         | 0                      | 1                     | 1                  | 1                     | 1 | 1    | R415 |
| 14    | Covers | R435                         | 1                      | 1                         | 0                         | 1                      | 1                     | 0                  | 0                     | 1 | 1    | R435 |
|       |        | R439                         | 1                      | 1                         | 0                         | 1                      | 1                     | 0                  | 1                     | 1 | 1    | R439 |
|       |        | R444                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 0                     | 0 | 0    | R444 |
|       |        | R445                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 1                     | 0 | 1    | R445 |
|       |        | R447                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 1                     | 1 | 1    | R447 |

**Table 1: Groups of relations, names, closure intersection and exterior intersections (continue)**

| Group | Name      | Closure intersections        |                        |                           |                           | Exterior intersections |                       |                    |                       |                    |      |
|-------|-----------|------------------------------|------------------------|---------------------------|---------------------------|------------------------|-----------------------|--------------------|-----------------------|--------------------|------|
|       |           | $\partial A \cap \partial B$ | $A^\circ \cap B^\circ$ | $\partial A \cap B^\circ$ | $A^\circ \cap \partial B$ | $A^- \cap B^-$         | $A^- \cap \partial B$ | $A^\circ \cap B^-$ | $\partial A \cap B^-$ | $A^\circ \cap B^-$ |      |
| 15    | CoveredBy | R467                         | 1                      | 1                         | 0                         | 1                      | 0                     | 1                  | 0                     | 1                  | R467 |
|       |           | R471                         | 1                      | 1                         | 0                         | 1                      | 0                     | 1                  | 1                     | 1                  | R471 |
|       |           | R476                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 0                     | 0                  | R476 |
|       |           | R477                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 0                     | 1                  | R477 |
|       |           | R479                         | 1                      | 1                         | 0                         | 1                      | 1                     | 1                  | 1                     | 1                  | R479 |
| 16    | Overlap   | R499                         | 1                      | 1                         | 1                         | 1                      | 0                     | 1                  | 1                     | 1                  | R499 |
|       |           | R501                         | 1                      | 1                         | 1                         | 1                      | 0                     | 1                  | 0                     | 1                  | R501 |
|       |           | R503                         | 1                      | 1                         | 1                         | 1                      | 0                     | 1                  | 1                     | 1                  | R503 |
|       |           | R508                         | 1                      | 1                         | 1                         | 1                      | 1                     | 1                  | 0                     | 0                  | R508 |
|       |           | R509                         | 1                      | 1                         | 1                         | 1                      | 1                     | 1                  | 1                     | 0                  | R509 |
|       |           | R511                         | 1                      | 1                         | 1                         | 1                      | 1                     | 1                  | 1                     | 1                  | R511 |

**Table 2: Possible relations between simple objects**

| Relation<br>(decimal) | Relation<br>(binary) | P,P | P,X | L,L<br>R | L,L<br>>R | L,S<br>R <sup>2</sup> | L,S<br>>R <sup>2</sup> | L,B | S,S<br>R <sup>2</sup> | S,S<br>>R <sup>2</sup> | S,B | B,B |
|-----------------------|----------------------|-----|-----|----------|-----------|-----------------------|------------------------|-----|-----------------------|------------------------|-----|-----|
| R026                  | 0000 1 1010          | ✓   |     |          |           |                       |                        |     |                       |                        |     |     |
| R030                  | 0000 1 1110          |     | ✓   |          |           |                       |                        |     |                       |                        |     |     |
| R031                  | 0000 1 1111          |     |     | ✓        | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   |
| R055                  | 0001 1 0111          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R063                  | 0001 1 1111          |     |     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     |
| R092                  | 0010 1 1100          |     | ✓   |          |           |                       |                        |     |                       |                        |     |     |
| R095                  | 0010 1 1111          |     |     |          | -         | -                     | ✓                      | -   |                       | -                      | -   |     |
| R117                  | 0011 1 0101          |     |     |          | ✓         |                       |                        |     |                       | ✓                      |     |     |
| R125                  | 0011 1 1101          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R127                  | 0011 1 1111          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R159                  | 0100 1 1111          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R191                  | 0101 1 1111          |     |     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     |
| R220                  | 0110 1 1100          |     |     | ✓        | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   |
| R221                  | 0110 1 1101          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R223                  | 0010 1 1111          |     |     |          | -         | -                     | ✓                      | -   |                       | -                      | -   |     |
| R245                  | 0111 1 0101          |     |     |          | ✓         |                       |                        |     |                       |                        |     |     |
| R252                  | 0111 1 1100          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R253                  | 0111 1 1101          |     |     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     |
| R255                  | 0111 1 1111          |     |     | ✓        | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      |     |     |
| R272                  | 1000 1 0000          | ✓   |     |          |           |                       |                        |     |                       |                        |     |     |
| R277                  | 1000 1 0101          |     |     |          | ✓         |                       |                        |     |                       | ✓                      |     |     |
| R284                  | 1000 1 1100          |     | ✓   |          |           |                       |                        |     |                       |                        |     |     |
| R285                  | 1000 1 1101          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R287                  | 1000 1 1111          |     |     | ✓        | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   |
| R316                  | 1001 1 1100          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R317                  | 1001 1 1101          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R319                  | 1001 1 1111          |     |     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     |
| R349                  | 1010 1 1101          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R373                  | 1011 1 0101          |     |     |          | ✓         |                       |                        |     |                       |                        |     |     |
| R381                  | 1011 1 1101          |     |     |          |           |                       | ✓                      |     |                       | ✓                      |     |     |
| R383                  | 1011 1 1111          |     |     |          |           |                       |                        |     |                       | ✓                      |     |     |
| R400                  | 1100 1 0000          |     |     | ✓        | ✓         |                       |                        |     | ✓                     | ✓                      |     | ✓   |
| R405                  | 1100 1 0101          |     |     |          | ✓         |                       |                        |     |                       | ✓                      |     |     |
| R412                  | 1100 1 1100          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R413                  | 1100 1 1101          |     |     |          |           |                       | ✓                      |     |                       |                        |     |     |
| R415                  | 1100 1 1111          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R444                  | 1101 1 1100          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R445                  | 1101 1 1101          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R447                  | 1101 1 1111          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R476                  | 1110 1 1100          |     |     | ✓        | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   |
| R477                  | 1110 1 1101          |     |     |          | ✓         |                       | ✓                      |     |                       | ✓                      |     |     |
| R501                  | 1111 1 0101          |     |     |          | ✓         |                       |                        |     |                       |                        |     |     |
| R508                  | 1111 1 1100          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R509                  | 1111 1 1101          |     |     |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     |
| R511                  | 1111 1 1111          |     |     |          |           |                       |                        |     | ✓                     | ✓                      | ✓   | ✓   |
| Number relations      |                      | 2   | 3   | 6+       | 23+       | 19                    | 31                     | 19  | 6+                    | 25+                    | 19  | 6+  |

**Table 2: Possible relations between simple objects (continue)**

| X,P | L,L<br>R | L,L<br>>R | S,L<br>R <sup>2</sup> | S,L<br>>R <sup>2</sup> | B,L | S,S<br>R <sup>2</sup> | S,S<br>>R <sup>2</sup> | B,S | B,B | Converse<br>Relation | Converse<br>Relation |  |
|-----|----------|-----------|-----------------------|------------------------|-----|-----------------------|------------------------|-----|-----|----------------------|----------------------|--|
| ✓   |          |           | ✓                     | ✓                      | ✓   |                       |                        | ✓   |     | 0000 1 1011          | R027                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0000 1 1111          | R031                 |  |
|     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0010 1 1101          | R093                 |  |
|     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0010 1 1111          | R095                 |  |
|     | ✓        |           | -                     | -                      | ✓   | -                     | -                      | -   |     | 0001 1 0011          | R051                 |  |
|     |          |           | -                     | -                      | ✓   | -                     | -                      | -   |     | 0001 1 1111          | R063                 |  |
|     |          |           | ✓                     |                        | ✓   |                       | ✓                      |     |     | 0011 1 0111          | R119                 |  |
|     |          |           |                       |                        | ✓   |                       | ✓                      |     |     | 0100 1 1111          | R127                 |  |
|     |          |           |                       |                        | ✓   |                       | ✓                      |     |     | 0101 1 1111          | R159                 |  |
|     |          | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   | 0110 1 1111          | R223                 |  |
| ✓   |          | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   | 0101 1 0011          | R179                 |  |
|     |          | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   | 0101 1 0111          | R183                 |  |
|     |          | -         | -                     | ✓                      | -   | -                     | -                      | -   | -   | 0101 1 1111          | R191                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0111 1 0011          | R243                 |  |
|     |          | ✓         | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0111 1 0111          | R247                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 0111 1 1111          | R255                 |  |
|     |          |           |                       |                        |     |                       |                        |     |     | -                    | -                    |  |
|     |          |           |                       |                        |     |                       |                        |     |     | -                    | -                    |  |
|     | ✓        |           |                       | ✓                      | ✓   | ✓                     |                        | ✓   |     | 1000 1 0011          | R275                 |  |
|     |          |           |                       | ✓                      | ✓   | ✓                     |                        | ✓   |     | 1000 1 0111          | R279                 |  |
| ✓   |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1000 1 1111          | R287                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1010 1 0011          | R339                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1010 1 0111          | R343                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1010 1 1111          | R351                 |  |
|     |          | ✓         |                       | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1001 1 0111          | R311                 |  |
|     |          |           |                       | ✓                      |     |                       | ✓                      |     |     | 1011 1 0111          | R375                 |  |
|     |          |           |                       |                        |     |                       |                        |     |     | -                    | -                    |  |
|     |          |           |                       | ✓                      | ✓   | ✓                     |                        | ✓   |     | 1100 1 0011          | R403                 |  |
|     |          |           |                       | ✓                      | ✓   | ✓                     |                        | ✓   |     | 1100 1 0111          | R407                 |  |
|     |          |           |                       | ✓                      | ✓   | ✓                     |                        | ✓   |     | 1100 1 1111          | R415                 |  |
| ✓   |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1110 1 0011          | R467                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1110 1 0111          | R471                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      | ✓   |     | 1110 1 1111          | R479                 |  |
|     | ✓        | ✓         | ✓                     | ✓                      | ✓   | ✓                     | ✓                      | ✓   | ✓   | 1101 1 0011          | R435                 |  |
|     |          | ✓         |                       | ✓                      | ✓   |                       | ✓                      |     |     | 1101 1 0111          | R439                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      |     |     | 1111 1 0011          | R499                 |  |
|     |          |           | ✓                     | ✓                      | ✓   |                       | ✓                      |     |     | 1111 1 0111          | R503                 |  |
|     |          |           |                       | ✓                      | ✓   |                       | ✓                      |     |     | 1111 1 1111          | R511                 |  |
|     | 3        | 2         | 10                    | 19                     | 31  | 19                    | 2                      | 13  | 19  | 2                    | Number relations     |  |



## Appendix 4: Guiding animation

A standard VRML syntax, which simulates moving around with a "car" (box) though the town when the user selects the option from the view menu. The highlighted co-ordinates are to be created with respect to the particular path.

```
#VRML V2.0 utf8
#March'97
#Sisi Zlatanova
# The carpet to move around

# ... initial information about the world

Group {
  children [
    DEF Clock TimeSensor {
      enabled FALSE
      cycleInterval 4.0
      loop TRUE
    }
    DEF Car Transform {
      translation 110 3 -220
      children [

        DEF CarView Viewpoint {
          position 0 0 0
          orientation 0 1 0 3.14
          jump TRUE
          description "on the carpet"
        }
        Shape {
          appearance Appearance {
            material Material {
              diffuseColor 0.60 0.30 0.2
              specularColor 0.8 0.8 0.8
            }
          }
          geometry Box {size 2 0.1 3}
        }
      ]
    }
  ]#end car
  DEF Path PositionInterpolator {
    key [ 0.0 0.10 0.20 0.30 0.4 0.50 0.6 0.7 0.8 0.9]
    keyValue [
      130 3 -207
      150 3 -208
      160 3 -208
      170 3 -209
      180 3 -209
      190 3 -208
      200 3 -200
      210 3 -190
      220 3 -180
      230 3 -170
    ]
  }
]
```

```
    }  
# ... the description of the world  
    ]  
}  
ROUTE CarView.isBound TO Clock.set_enabled  
ROUTE Clock.fraction_changed TO Path.set_fraction  
ROUTE Path.value_changed TO Car.set_translation
```