# Geographic Information and Virtual Systems
## - From Vision to Reality

*Patrik Ottoson, Utvecklingsrådet för Landskapsinformation*

***The vision***

*The main idea of three-dimensional visualisation is to use computer-imaging technology in order to realise and understand information, which is obtained by simulation or physical measurement (Haber and McNabb 1990). In this manner, scientists and engineers can extract knowledge and existing scientific methods can be influenced by providing additional insights through visual methods (McCormick et al. 1987). Visualisation unifies, for example, computer graphics, image processing, computer vision, CAD, signal processing, and user interface design. Within the area of geographic information, visualisation can be used to better understand city planning, architecture, environment, and other fields with a geographic component.*

*The visions are and were many. The word ”cyberspace” was coined in 1984 in the novel Neuromancer (Gibson 1984). Fantasy images of people being immersed into ”cyber worlds” were drawn. It was just a matter of time before we could have cyber-travels, cyber-terrorism, and cyber-sex at the office or in the living room. The era of three-dimensional visualisation had its peak in the mid-90's. Unfortunately, the era was short and the boom never occurred. The reason was obvious – visualisation is just a tool to obtain results in connection to other fields. There were also a number of technology failures or limitations. Today, the industry tries to put visualisation into practical use and connect it to real problems. The visions will still be there, but the reality controls the development.*

**Virtual Reality**

Visualisation is a large topic. Some will probably say that any presentation and rendering tool can be subordinated the definition of this word, *e.g.* cartography, virtual reality as well as simple drawings and sketches. Three-dimensional visualisation is for many persons equal to Virtual Reality. The concept of Virtual Reality was introduced in 1929 when Edwin Link created the first flight simulator. Jaron Lanier invented in 1989 the term ”Virtual Reality”. The notion of Virtual Reality can be traced back to Myron Krueger in the 1960's, and Morton Heilig and Ivan Sutherland before that (Heim 1993). Heilig can be considered as the founder of Virtual Reality (Rheingold 1992).

The correct and strict definition of Virtual Reality implicates that three-dimensional visualisation should be supported by special display devices and responsive equipment. The Virtual Reality device should serve as many senses as possible (Sutherland 1965). Virtual Reality is sometimes defined by its depth of *immersion*. Immersion means to plunge into the virtual environment. The largest effect on visual immersion is the field of view, the frame rate, the colour depth, and the image resolution. A ”true” Virtual Reality system has 100% immersion. In such an immersion, the observer should have the feeling of being entirely inside and surrounded by the virtual environment. Immersion is also important in the meaning of cognitive and sensory apparatus, not only the display unit. This means that all ”stuff” lying between people and computers have to be considered (Negroponte 1981). Heim (1993) defines seven concepts guiding the research on Virtual Reality: simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and networked communication. Responsive environments are essential for real-time interaction between man and machine (Krueger 1977).

**The history is 8200 years old**

The first known map was produced 6.200 BC. It shows a twin cone of the erupted volcano Hasan Dag, which arises 10.672 feet at the east of the Konya Plain in Turkey (Figure 1). The volcano is presented as a view from another place called Çatalhöyük. Even this map has a projection, but of course, no strict perspective projection was used. Another early map, sometimes called ”earliest know map” is the Babylonian clay tablet, which is dated 2.500 BC.

The development of producing and constructing maps were forced by wars, disasters, and taxation. During several hundred years, geodetic survey was

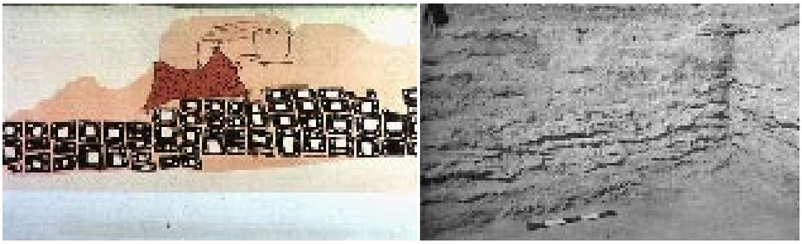

*Fig. 1. The oldest known map. It shows the volcano Hasan Dag.*

the predominated method. The first practical photograph was announced to the French Academy of Arts and Sciences in 1839 and the first aerial photographs were attempted by Laussedat in France in 1858. In the beginning of the 20th century, photographs and photogrammetry made it possible to produce maps more effectively. The topographic maps were produced by transferring objects from the photographs to a paper or plate. The relationship between the perspective and orthogonal projection was used.

**The principles are 600 years old**

The history of three-dimensional visualisation goes back several hundred years. Three-dimensional visualisation is built on the perspective projection, whether it is presented on an analogue paper, on a photographic film, or on a computer screen. The basic principles are the same. Architects and artists invented methods to apply and determine the perspective projection six hundred years ago. Filippo Brunelleschi was the first architect, in the beginning of the 15th century, to employ mathematical perspective to redefine space and to establish rules of proportioning and symmetry (Figure 2).

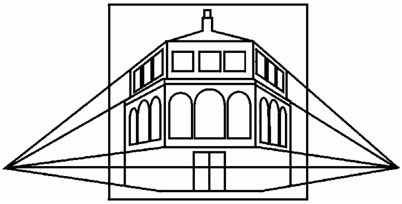

Fig. 2. The basic principles of the perspective projection. The lines of the facade intersect in two vanishing points, which can be used to determine the perspective projection (Ottoson 1999).

In visualisation, a Cartesian, right-handed, three-dimensional co-ordinate system is used. Objects are projected onto a two-dimensional device by projecting them in the direction of the positive Z-axis, with the positive X-axis to the right and the positive Y-axis up (Figure 3). A positive Z-axis means that the axis is coming out of the screen (towards you). A modelling transformation may be used to alter this default projection.

Virtual worlds may contain an arbitrary number of local or "object-space" co-ordinate systems. These are defined by modelling transformations using Translate (**T**), Rotate

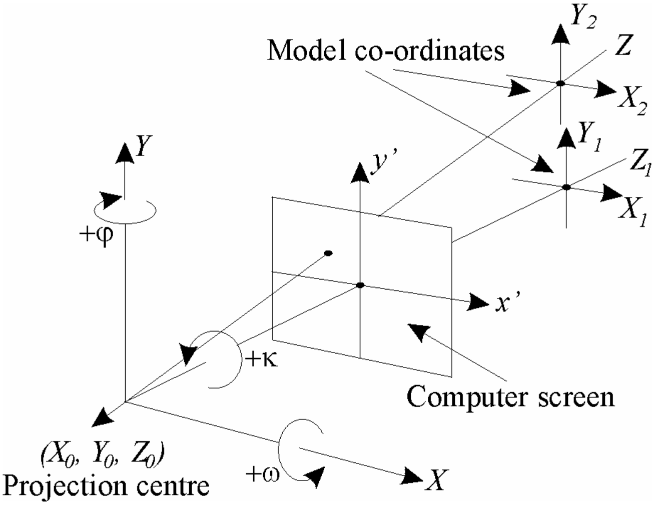


*Fig. 3. A Cartesian, right-handed, co-ordinate system. The "image plane", i.e. the computer screen, is placed in front of the projection centre.*

(**R**), Scale (**S**), Transform, and MatrixTransform nodes. A vertex **V** (the co-ordinates is defined as a 1x3 vector) is transformed in the following order: $\mathbf{V'} = \mathbf{T} \cdot \mathbf{R} \cdot \mathbf{S} \cdot \mathbf{V}$.

Conceptually, virtual worlds has one world or model co-ordinate system and one viewing or "camera" co-ordinate system. The transformations map the objects into the world co-ordinate system (X, Y, Z) and this is where the scene is assembled. The scene is then viewed through a "camera", which has another co-ordinate system (x′, y′).

The mathematical formalism of three-dimensional visualisation is analogous to the formalism of a camera's central projection used in photogrammetry and computer vision. The relationship between a model co-ordinate (the objects), $\mathbf{U}_i$, and an image co-ordinate (what is presented on the screen), $\mathbf{u}_i$, is expressed as

$$\mathbf{u}_i = \mathbf{AR}\left(\mathbf{I} \middle| - \overline{\mathbf{P}}_0\right)\mathbf{U}_i$$

**A** describes the camera parameters, $\overline{\mathbf{P}}_0$ is the camera position (projection centre), **I** is the identity matrix, and **R** is the rotation matrix. Thus, the visualisation process allows translation, rotation, and change of scale. The equation implies that all positions have to be presented as normalised model co-ordinates. Thus, geographic objects have to be scaled and translated before they are handled by the geometry engine.

**The Components and Mechanisms**

Visualisation is a tool to understand things better. To enable this, visualisation has to be supported by technology. In Figure 4, a conceptual model of geographic visualisation is shown. The visualisation technology consists of three fundamental *components*: data, graphics, and interfaces. Data can be structured in suitable models having a specified accuracy. The graphic component controls rendering of data (*e.g.* 3D and animation). Interfaces make it possible for the user to interact with and to display data. Visualisation has three fundamental *mechanisms*: data management (*e.g.* of a database), computation (*e.g.* analysis and simulation), and data acquisition. The visualisation system/model can also be divided into a *concealed part* and a *visual part*. In the concealed part, data are acquired, stored, and managed. This part is usually transparent for the end user, *e.g.* a city planner and GIS analyst. In the visual part, data are transformed into information, understandable for the end user.

**The Reality**

Visions come with the reality and possible solutions. The development of three-dimensional visualisation and Virtual Reality is driven by technology. The visualisation in, for example, the VRML-browser has been demonstrated as a good tool and it can used for practical problems. The topics and areas where geographic

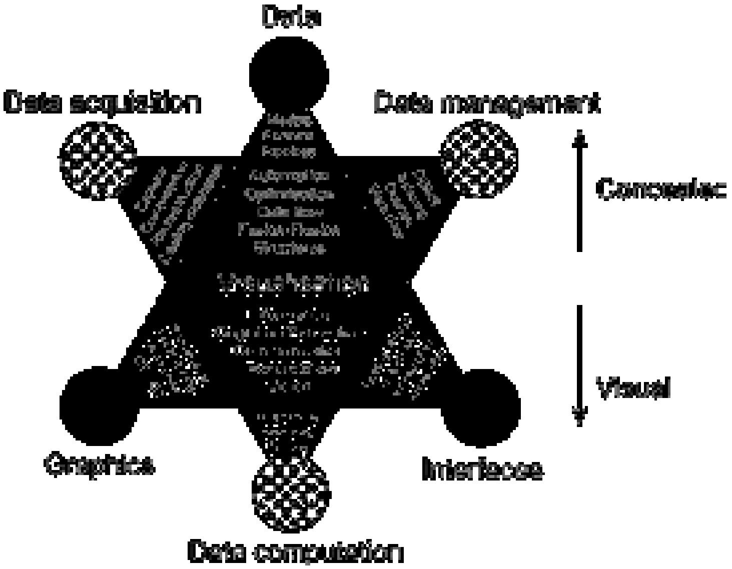


*Fig. 4. A conceptual model of geographic visualisation (Ottoson, 2001).*

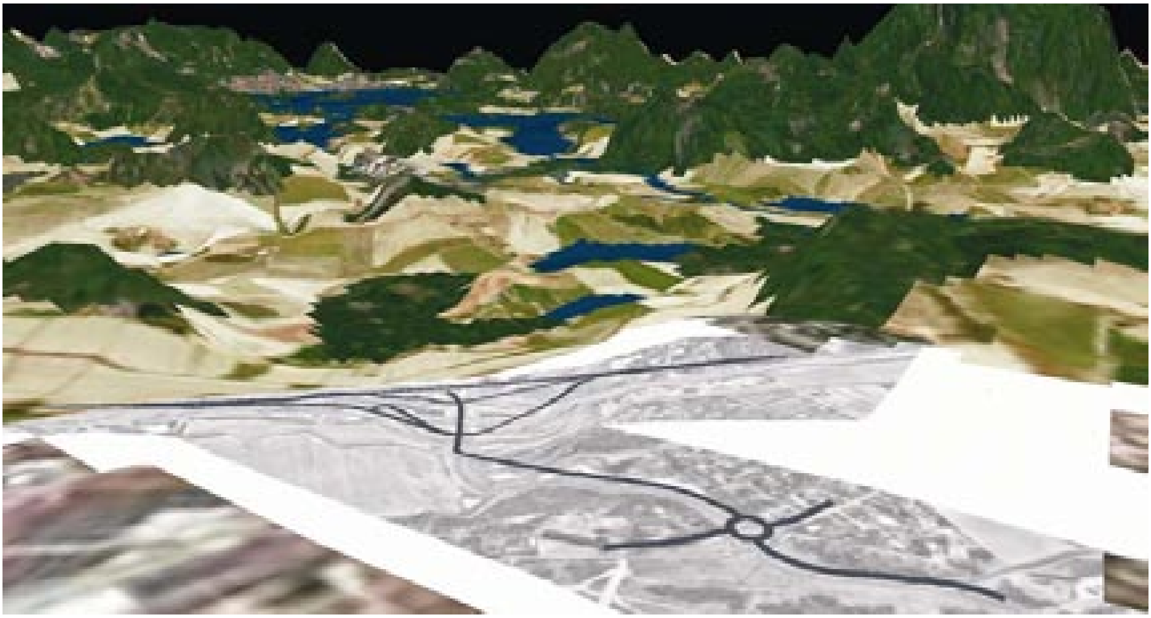

*Fig. 5. The rendered scene of a road junction is constructed from a digital orthophoto, a terrain model, artificial textures, and road data.*

visualisation is used today and shows good potential are city planning, architecture, road planning and design, construction, and just pure visualisation in many planning processes (Figure 5). Many geographic information systems (GIS) implement visualisation tools, like fly-through, interaction, and animation (e.g. time-sequence visualisation). By that, it can be easier to analyse and draw conclusions for specific projects.

The research within Virtual Reality is partly concentrated on display units, because suitable equipment for "true" three-dimensional visualisation does not yet exist. Most equipment either produces artefacts (e.g. high objects vanish on flat screens) or has limitations (e.g. resolution, colour-space, frame rate, single user, and data transfer). The most common techniques are back- and front-projection, head-mounted displays, and lenticular screens (Figure 6):

- Back- and front-projection – So called spatially immersed displays (SID) have an ultra-wide field of view and they can have the shape of a cylinder, a dome, a torus, or a rectilinear (Wright 2000). Virtual model displays (VMD) are less immersive than SIDs, but they are valuable for working with models that fit on a workbench (Bolas et al. 1997; Agrawala et al. 1997; Krüger and Fröhlich 1994). The CAVE (CAVE Automatic Virtual Environment) is an example of a back-projection SID. The CAVE is a cave/box with visualisation on four walls, floor, and ceiling (Cruz-Neira et al. 1992, 1993).
- Head mounted displays (HMD) – A HMD can be mounted on the observer's head. The technology was invented to place a human inside computer-generated graphic simulations (Sutherland 1968). HMDs are apt to convey a feeling of total immersion (Teitel 1990; Pastoor and Wöpking 1997).
- Lenticular screens - These screens consist of a large number of small lens elements (a few millimetres in diameter). The lens elements are used to bend the rays coming from, for example, a LCD projector and the rays passing each pixel are bent differently (Takemori et al. 1995; Börner 1993; Omura et al.


*Fig. 6. Virtual Reality displays: back-projection, HMD, and lenticular screen.*

1995). For instance, three different perspectives can be obtained by placing series of three pixels next to each other.

There exist other advanced technology to make the virtual world realistic. While back- and front-projection, HMD, and lenticular screens can be bought from the shelf, there are others under heavily development, such as holographic screens and volumetric imaging. These two have a great potential, because the number of simultaneous users is unlimited and no specific spectacles are needed. The main idea with Virtual Realtiy is to collaborate with other people. Therefore, it is very important to support multiple users and not cover a communication source (*i.e.* our eyes). The techniques of holographic screens and volumetric imaging can be described as (Figure 7):

- *Holographic screens* – The holographic screens do not require any special viewing device, like HMD or shutter glasses (Hashimoto and Morokawa 1995; Nishikawa and Okada 1997; Honda 1995). This is essential in multi-user systems, because it makes possible eye-to-eye communication.
- *Volumetric imaging* – A two- or three-dimensional matrix is used to display three-dimensional data. The imaging unit can be shaped like a cylinder or a sphere. Each element of the imaging unit can artificially be activated with a rotating array of LEDs (Solomon 1992, 1993) or using a volumetric 3D-laser display (Bahr *et al.* 1996). Another way of obtaining volumetric images is to illuminate a semitransparent helix with a laser (Soltan *et al.* 1995).

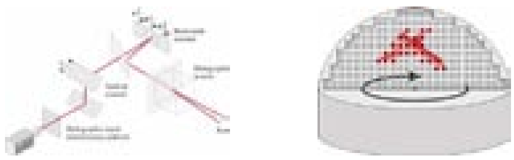

*Fig. 7. Virtual Reality displays: holographic screen and volumetric imaging.*

**Networked communication and interaction**

In the beginning of this section, we argue that tele-presence and networked communication were essential parts in Virtual Reality technique. These two parts are somehow connected. Presence may mean both physical and teleported presence. Sommerer *et al.* (1999) showed that telepresence could be obtained in virtual environments by using video cameras that capture a stream of monoscopic images of two persons from separate places and superimpose them into a three-dimensional environment. Networked communication is the tool to get presence, and the communication can be performed through the Internet. This means that Internet visualisation and Virtual Reality can be achieved without involving simple VRML-browsers. In this case, data and information are sent through high-speed communication and the virtual environments are shared by two or more interactive users. Standard software may be used for such applications in the future (figure 8). One of the goals

*Fig. 8. An imagined model with interaction, physical and tele-ported presence, and collaboration in a virtual environment through the Internet.*

with, for example, VRML 2.0 is to support interaction and collaboration.

Interaction in a VRML-browser is usually performed via the mouse and the control board of the browser (Goralski *et al.* 1996). The control board allows simple movement of the objects, like scaling, translation, and rotation (figure 16). In more advanced browsers, it is possible to interact with three-dimensional interaction utilities. The utility can, for example, be a ”stylus”, a 3D-ball, ”pinch gloves” or ”phantoms”. All these utilities are physical and make it possible to actually interact in three dimensions, because you move the utility in real space. The so-called ”phantom” can also be used to feel weight and inertial power. The movement of the utility steers the cursor, which can be used to create, grab, move or change objects.

**Conclusions**

Three-dimensional visualisation and Virtual Reality can be used for a large number of applications. Some have already been mentioned, but to identify others: explanatory sightseeing (*e.g.* presentation on museums and companies), world heritage presentations, games, three-dimensional visualisation of landscapes, rescue training, modelling, analyses, and navigation systems. At the time of writing, the Swedish National Post and Telecom Agency decided that the license-free construction of the Swedish 3G-telecom network has to be developed as contracted, with three actors. This will probably be an important step and will put Sweden into a leading position in the area of Location-based services (LSB) and mobile Internet. The new electronic mobile services have been given the name m-services. There are three important steps, which control the market of geographic information; namely information, infrastructure, and services. Visualisation of the future will definitely not be the same as today. It will be more closely connected to real solutions and services, where the mobility will be the key to a better and more effective future.

**References**

Agrawala M., Beers A., McDowall I., Fröhlich B., Bolas M., and Hanrahan P. 1997, *The Two-user Responsive Workbench: Support for Collaboration Through Individual Views of a Shared Space*. In Proceedings of SIGGRAPH ’97, Los Angeles, CA: 327-332

Ames A., Nadeau D., and Moreland J. 1997, *The VRML 2.0 Sourcebook*. John Wiley & Sons. ISBN 0-471-16507-7

Bahr D., K. Langhans, M. Gerken, C. Vogt, D. Bezecny, and D. Homann 1996, FELIX: *A Volumetric 3D Laser Display*. In Proceedings of SPIE Volume: 2650, Projection Displays II, San Jose, CA: 265-273

Bolas M. T., Bryson S., and McDowall I. 1997, *Virtual Model Displays*. In Proceedings of SPIE Volume: 3012, Stereoscopic Displays and Virtual Reality Systems IV, San Jose, CA: 429-438

Börner R. 1993, *Autostereoscopic 3D-imaging by Front and Rear Projection and on Flat Panel Displays*. Displays 14(1): 39-46

Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R., and Hart, J.C. 1992, *The CAVE, Audio-visual Experience Automatic Virtual Environment*. Communications of the ACM 35(6): 67-72

Cruz-Neira C., Sandin D., and DeFanti T. 1993, Surrounded-screen Projections-based Virtual Reality: *The Design and Implementation of the CAVE*. In Proceedings of SIGGRAPH '93. Anaheim, CA: 135-142

Gibson W. 1984, *Neuromancer*. New York. ISBN: 0-441-56959-5

Goralski W., Poli M., and Vogel P. 1996, *VRML: Exploring Virtual Worlds on the Internet. Prentice Hall*. ISBN 0-13-486960-5

Haber R.B., and McNabb D.A. 1993, *The Metaphysics of Virtual Reality.* Oxford University Press. ISBN 0-19-508178-1

Hashimoto N., and Morokawa S. 1995, *Motion-picture Holography using Liquid-crystal Television Spatial Light Modulators.* In SID 95 Digest: 847-850

Heim M. 1993, *The Metaphysics of Virtual Reality.* Oxford University Press. ISBN 0-19-508178-1

Honda T. 1995, *Dynamic Holographic 3D Display using LCD.* In Proceedings of Asia Display, Hamamatsu, Japan: 777-780

Krueger M. 1977, *Responsive Environments.* In Proceedings of the AFIPS National Computer Conference, Dallas, TX: 423-433

Krüger W. and Fröhlich B. 1994, *The Responsive Workbench*. IEEE Computer Graphics and Applications 14(3): 12-15

McCormick B., DeFanti T. A., and Brown N. D. 1987, *Visualization in Scientific Computing*. ACM SIGGRAPH Computer Graphics 21(6): 3-14

Negroponte N. 1981, *Media Room.* In Proceedings of the Society for Information Display 22(2): 109-113

Nishikawa O. and Okada T. 1997, *High-speed Holographic-stereogram Calculation Method using 2D FFT.* In Proceedings of SPIE Volume: 3010, Diffractive and Holographic Device Technologies and Applications IV, San Jose, CA: 49-57

Omura K., Shiwa S., and Kishino F. 1995, *Development of Lenticular Stereoscopic Display Systems: Multiple Images for Multiple Viewers.* In SID 95 Digest: 761-764

Ottoson P. 1999, *Determination of Orientation Elements of Facade Images Provided Known Interior Orientation.* Bildteknik/Image Science 2: 5-18

Ottoson P. 2001, *Geographic Indexing and Data Management for 3D-Visualisation.* Ph.D. Thesis, Royal Institute Technology, KTH, Sweden

Pastoor S. and Wöpking M. 1997, *3-D Displays: A Review of Current Technologies.* Displays 17(2): 100-110

Reddy M., Iverson L., and Leclerc Y. G. 2000, *Under the Hood of GeoVRML 1.0.* In Proceedings of Web3D/VRML: the 5th Symposium on the Virtual Reality Modeling Language, Monterey, CA: 23-28

Rheingold H. 1992, *Virtual Reality.* London Mandarin. ISBN 0-7493-0889-3

Solomon D. J. 1992, *Volumetric Imaging Innovations for 3D Workstations.* In Proceedings of CAD and Engineering Workstations'92 and Business Graphics'92 Conference and Exposition, Fairfax, VA: 746-752

Solomon D. J. 1993, *Volumetric Imaging Launches Graphics into a 3-D World.* Photonics Spectra 6: 129-134

Soltan P., Lasher M., Dahlke W., Acantilado N., and McDonald M. 1995, *Laser Projected 3-D Volumetric Displays – Second Generation.* Interactive Technology and the New Paradigm for Healthcare, IOS Press: 349-357

Sommerer C., Mignonneau L., and Lopez-Gulliver R. 1999, *Time-lapse: immersive interaction with historic 3-D stereo images.* In Proceedings of International Conference on Virtual Systems and Multimedia, Dundee, Scotland: 295-307

Sutherland I. 1965, *The Ultimate Display.* In Proceedings of the IFIP Congress, New York City: 506-508

Sutherland I. 1968, *A Head Mounted Three-dimensional Display.* In Proceedings of the Fall Joint Computer Conference, Thompson Books, Washington, DC: 757-764

Takemori D., Kanatani K., Kishimoto S., Yoshi S., and Kanayama H. 1995, *3-D Display with Large Double Lenticular Screens.* In SID 95 Digest: 55-58

Teitel M. 1990, The Eyephone, *A Head Mounted Stereo Display.* In Proceedings of SPIE Volume: 1256, Stereoscopic Displays and Applications: 168-172

Wright D. 2000, *Survey of Projection-based Immersive Displays.* In Proceedings of SPIE Volume: 3957, Stereoscopic Displays and Virtual Reality Systems VII: 482-49


**Om forfatteren**

Utvecklingsrådet för Landskapsinformation, ULI, SE 801 82 Gävle, Sverige,
e-mail: patrik.ottoson@lm.se