SUPPORT FOR VISUALISATION AND ANIMATION IN A SCALABLE 3D GIS ENVIRONMENT – MOTIVATION, CONCEPTS AND IMPLEMENTATION

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ABSTRACT:

The establishment and visualisation of large, reality-based 3D landscape and city models has received significant attention over the last few years – both in the scientific and the commercial community. Recent progress in 3D data capturing and web-based visualisation technologies are opening up new possibilities for a wide-spread use of 3D landscape models as a basis for new and exciting information and entertainment services. However, with the rapidly increasing size and complexity of the 3D models being acquired, a pressing need for suitable data management solutions has become apparent. This paper outlines why 3D GIS technologies are a key factor in establishing and maintaining large-scale, reality-based 3D geoinformation services. It also discusses specific features which should be provided by such 3D GIS in order to support the efficient visualisation and animation of reality-based landscape and city models. The aspects of managing reality-based 3D models within a 3D GIS environment are being investigated as part of the DILAS (Digital Landscape Server) project. DILAS is a fully DBMS-supported framework – and now a commercial product line – combining object-relational and XML technologies for the integrated management of very large 3D landscape and city models. The system provides a comprehensive support for colour, transparency, textures as well as animations and view control. This support for reality-based 3D models within a 3D GIS environment enables the automated generation of web-based 3D scenes with user-defined contents and appearance. The paper concludes with the presentation of pilot projects from application areas which will largely benefit from the functionality presented above.

1. INTRODUCTION

1.1 Motivation

Reality-based 3D models are being acquired in a variety of application domains ranging from archaeology, urban planning and simulation to computer games. Each of these domains has its specific requirements which led to the development of application specific solutions focussing on the primary needs of each specific domain. In some domains the primary focus is placed on 3D objects with a maximum level of detail and a high degree of realism. In others it is placed on spatial context requiring the inclusion of large geospatial data sets. However, all applications relying on reality-based 3D models also have a lot of aspects in common, namely the need for efficient data handling and access and the increasing demand for dynamic contents.

Geographical Information Systems (GIS) and namely 3D GIS will play an important role in bridging the existing gaps between the different application domains. This paper will demonstrate some of the benefits of 3D GIS support for the establishment and maintenance of reality-based 3D models in general and for their visualisation and animation in particular.

1.2 Current Status and Activities

In the geospatial domain reality-based 3D models have received considerable attention from a number of perspectives, namely 3D data capturing, 3D visualisation and 3D data modelling and management.

3D Data Capture – There has been a lot of research work and considerable progress in the field of 3D data capture. Some 3D data capturing methods, such as the automatic generation of terrain models from aerial imagery or laser scanning, are now fully operational. The reconstruction of 3D objects, namely buildings, has reached a semi-automated level with reasonable production rates. Ongoing work is focussing on the integration of multiple sensors, namely aerial imagery and laser scanning in order to further increase the robustness and productivity of the 3D data acquisition process. An increasingly important aspect is the efficient acquisition, correction and assignment of object textures. (Haala and Brenner, 2001), (Grün et al., 2002)

3D Geovisualisation – There has been significant progress in the visualisation of landscape and city models. Over the last couple of years we have seen the emergence of first operational web-based solutions for the visualisation of very large landscape models. Advanced software solutions together with powerful 3D graphics on standard PCs and gradually increasing network bandwidths have turned geovisualisation from a specialist to a mass market application. Some of the ongoing developments are focussing on the streaming of very large numbers of 3D objects, such as encountered in large city models, and on enabling high-performance 3D visualisations on mobile devices. (Kraak et al., 2002; Nebiker, 2001)

3D Data Modelling and Management – Over the last few years we have seen an increasing amount of work in the field of modelling and managing geospatial 3D objects. A number of projects were focussing on the modelling and management of complex 3D objects – in a primarily relational DBMS environment, e.g. (Pfund, 2001), (Wang, 2000). Some ongoing projects employ object-relational concepts to address the issues of topology (Oosterom et al., 2002) and integrated 3D geodata management within a 3D GIS framework, e.g. (Nebiker, 2002a), (Zlatanova et al., 2002).

1.3 Limitations and Challenges

Despite the considerable progress in the above mentioned research areas, there are still a number of limitations, namely in the fields of integration and usability of reality-based 3D models. Some of the main limitations include:

- the absence of multi-user support and interoperability in 3D production and exploitation environments
- a primarily graphics-oriented modelling functionality and a limited or missing support for semantics
- a lack of support for managing and exchanging reality-based appearance information and animations in the prevailing CAD formats and platforms
- a missing or inefficient re-usability of 3D city models

Today's situation with regards to the production and use of reality-based 3D models can be best described as collections of 'island solutions' – in terms of space, time, context and accessibility. This is illustrated by the following example with three different 3D models of the Roman City of Augusta Raurica near Basel in Switzerland:

- Detailed 3D model of 'Insula 30', one of the ancient city blocks of Augusta Raurica (Figure 1). The CAD-based reconstruction and reality-based visualisation of this model was carried out in close collaboration between archaeologists and geomatics specialists.
- Complete 3D city model of the ancient city of Augusta Raurica (Figure 2). This model was reconstructed from an existing wooden model at a scale of 1:500 using close-range photogrammetry.
- City model of the modern town of Augst which was built 'on top' of Augusta Raurica (Figure 3). This city model was acquired using digital aerial photogrammetry.

All these models cover roughly the same geographical location and were all acquired by students of the FHBB. However, they cover different temporal epochs, they were acquired in different system environments with different formats and as a consequence their semantic models are either undefined or at least inhomogeneous and incompatible. Integrating these different 3D models into a coherent, interoperable geoinformation framework would greatly enhance the usability and benefits of such interdisciplinary geoinformation applications.

Figure 1: Detailed reality-based archaeological 3D reconstruction of the ancient city block 'Insula30'.

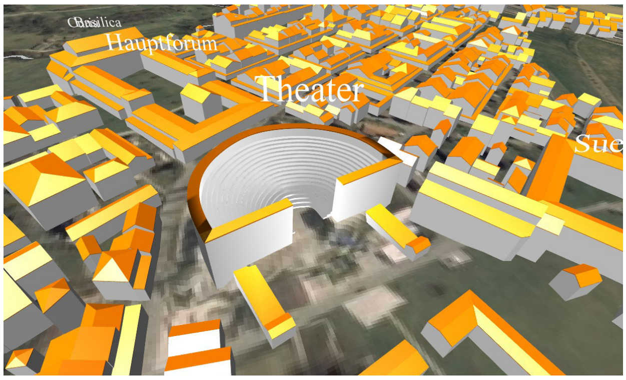

Figure 2: 3D city model of the ancient city of Augusta Raurica.

Figure 3: 3D city model of the modern city of Augst.

In the following sections we will focus on the contributions of modern 3D GIS solutions towards a better integration and usability of large, reality-based 3D models.

2. 3D GIS AND REALITY-BASED MODELS

2.1 Typical GIS Functionality

Before looking at the benefits of a 3D GIS in the context of reality-based 3D models it might be worthwhile to recapitulate some of the basic functionality of a GIS. This basic functionality covers the aspects of modelling, acquisition, management and manipulation, analysis, presentation and exchange of geodata. The modelling functionality and the underlying geospatial data models need to support the aspects of geometry, topology, semantics and presentation. Current reality-based 3D solutions are often focussed on the aspects of data acquisition and visualisation or geometry and presentation respectively. They typically do not cover the other aspects of a geoinformation system.

From a less conceptual and more practical perspective there are a number of additional requirements, which a modern GIS should fulfil and which are particularly relevant for large and complex reality-based 3D models:

- geometric and semantic modelling power and flexibility
- performance and scalability
- interoperability
- extensibility
- separation of presentation model and spatial model
- support for multiple representations

2.2 Modelling and Management of 3D Landscapes

The representation of reality-based 3D landscape and city models requires a variety of spatial data types. These include orthoimagery and terrain data, vector-based 3D and 2D geo-objects, object textures, 3D scene objects, points of interest (POI), animations and hyperlinks (Figure 4) (Nebiker, 2002a). These data types have very different characteristics and requirements in terms of management and visualisation. The spectrum ranges from very large spatial objects, such as orthoimagery and high-resolution DTM data, with data volumes in the order of Terabytes to large numbers of complex and possibly dynamic 3D objects. However, all these data types should ideally be integrated into a single geodatabase architecture.

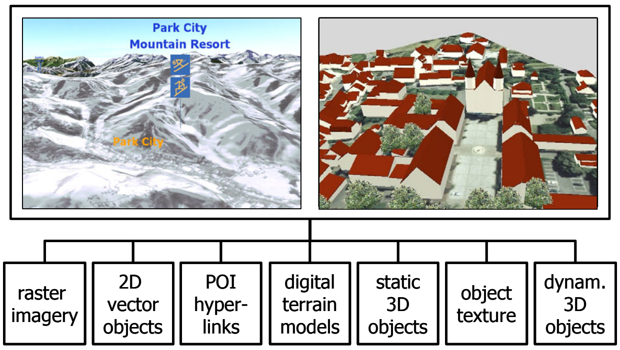

Figure 4: Components of a 3D landscape model.

2.3 Why 2D GIS is not the Answer

Currently a number of major GIS vendors are adding 3D visualisation support to their 2D GIS products. This approach yields some rapid and attractive results since it gives the 3D visualisation component access to the existing and often extensive 2D geodatabases. However, a closer look reveals a number of shortcomings, namely:

- missing DBMS support for 3D objects, which means no or limited multi-user support, access control etc.
- often no DBMS support for other data types such as elevation data an terrain texture (orthoimagery and maps)
- no integrated support for object textures

The following points will explain why some of these limitations are of quite fundamental nature and why 3D GIS is not just 2D plus an additional dimension.

- *Modelling complexity* – Reality-based 3D objects are normally far more complex than 2D geospatial objects. A reality-based geospatial 3D object, for example, typically consists of a considerable number of 3D elements, of which each could possess its own semantics and appearance information (e.g. element X is a façade element consisting of copper or glass).
- *Multi-resolution and multi-representation* – In a 2D GIS environment there is always just one representation or resolution per view – at least just one per object class. In a truly scalable 3D environment, as a general rule, there are always multiple resolutions or representations per 3D view.
- *Degree of freedom and viewer dynamics* – In a 2D environment, the degree of freedom and the level of interactivity are far more restricted than in a 3D environment. This applies to the viewing position, to the viewing direction, the field of view, the viewer motion and the interaction with geospatial objects (e.g. entering a building, passing over or under a bridge).
- *Presentation and appearance* – The presentation model of 2D GIS is primarily focussed on a symbolised or cartographic representation of geoinformation; with the exception of orthoimagery backdrops. Thus, the support for reality-based geospatial objects has to be addressed from scratch.

2.4 Support for Visualisation and Animation in a 3D GIS

It was already pointed out that the aspects of reality-based appearance and animation play a far more important role in a 3D environment than in traditional 2D GIS. The following list shows some of the visualisation and animation issues which need to be addressed in the context of reality-based 3D models:

- *3D object appearance* includes support for colour, transparency, generic or reality-based object textures as well as attribute-based appearance control. Quite often, the same 3D object might have different appearance settings, depending on the application and context in which the object will be used (see also section 4.1.1).
- *Viewpoint information* includes viewer position and attitude, angle of view, viewpoint descriptions etc. In 3D geoinformation solutions, there is a need for object-specific viewpoint information. For example, a certain 3D object (building or landmark) is ideally viewed from specific locations in order to get an optimal impression. These ideal viewpoints usually cannot be determined automatically and thus should be stored and re-used.
- *Scene lighting* – An ideal reality-based visualisation of certain 3D objects might require regional or object-specific lighting settings.
- *Animation* of scene contents and viewer position – includes information on animation path, speed, attitude etc.
- *Simulations / Temporal representations* of scene contents

Traditionally, many of these issues are handled in a specific 3D visualisation or editing environment and are stored in proprietary formats. Due to the absence of common repositories for this 'auxiliary' scene data, re-usability of this important and costly information is usually quite poor.

As a minimum requirement, a 3D GIS environment should support different types of 3D object appearances (multiple representation models) and/or the on-the-fly generation of specific object presentations, based on user-selectable parameters (e.g. show all public buildings in a semi-transparent orange colour).

3. THE DILAS 3D GIS

3.1 Overview

DILAS (Digital Landscape Server) is a comprehensive 3D GIS platform for the integrated management of regional to national 3D landscape and city models and for the generation of web-based geoinformation services (Nebiker, 2002a). DILAS™ is a commercial product line of GEONOVA AG (www.geonova.ch) and it serves the FHBB as a platform for applied research and development.

The next section highlights some of the key concepts developed and implemented as part of the DILAS project: a flexible 3D object model, a multi-representation and multi-resolution approach for the different object types, a storage concept for 3D and raster objects and XML-based process rules.

3.2 DILAS Concepts

3.2.1 3D Object Model – One of the key concepts of the DILAS project is a generic, fully object-oriented model for 3D geo-objects. This object model incorporates a 3D geometry model (Figure 5) which is based on a topologically structured 3D boundary representation and which supports most basic geometry types (points, lines, planar and non-planar shapes as well as a number of geometric primitives). It incorporates the capability for multiple levels of detail (LOD) as well as texture and appearance information. The 3D object model is suitable for representing any spatial topic (e.g. buildings, bridges, power-lines).

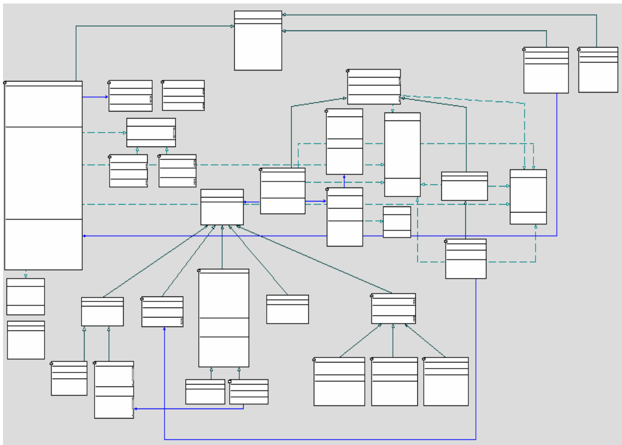

Figure 5: DILAS 3D object model (overview).

The DILAS 3D object type is supplemented by a number of spatial data types used for representing very large mosaics of high resolution terrain and texture data:

- raster maps
- orthoimagery
- terrain and surface models (regular grids)
- terrain and surface models (irregular point clusters), e.g. for managing very large laser scanning height data sets

The concept for the DILAS 3D object model already incorporates visualisation-related features such as viewpoints and lighting information. In addition the model has been explicitly defined to easily cater for future extensions, such as animation paths etc.

3.2.2 Multi-Representation and Multi-Resolution – Two key issues in the efficient management and visualisation of large 3D models are multiple representation and multiple resolution. Different multi-representation strategies were developed for the spatial object types used in DILAS. The original multi-resolution approach for managing very large raster mosaics (Nebiker, 1997) was further refined and extended to all mosaic types listed above.

3D objects are represented by 3D bounding boxes, 2D object boundaries and the actual 3D geometry (Nebiker, 2002c). The first two representations are essential for efficient query operations and are automatically derived from the main 3D representation.

3.2.3 Storage Concept for 3D Objects – The goal for handling and manipulating 3D objects was to provide an optimum modelling flexibility in combination with an excellent object query and retrieval performance. The developed concept is based on the following components:

- a 3D object representation in Java and XML
- a 3D object serialisation and de-serialisation
- a persistence framework built on top of the DBMS
- spatial data types for 3D and raster objects within an object-relational environment

A number of these mechanisms are adapted from modern object-oriented programming environments. The object serialisation approach, for example, permits to map very complex objects to a simple, but highly efficient storage mechanism. The storage mechanism is based on a type extension for 3D objects which encapsulates the actual large object based (LOB) object storage.

The persistence framework developed in DILAS adapts concepts from the Java Data Objects (JDO) extension. It permits a fine-grained control over changes to the 3D object properties.

3.2.4 XML-based Process Rules – The processes of importing, structuring, generating and validating 3D city models are quite complex and typically differ from organisation to organisation, e.g. different level assignments, exchange of geometry only versus exchange of actual 3D objects etc.

The goal of accommodating these diverse requirements led to the development of a mechanism using 'XML-based process rules'. The benefits of this rule-based approach are:

- The possibility of formally specifying valid processing options (e.g. data import options) through the means of different XML Schemas.
- The easy adaptation of process rules or the creation of new process rules by a project leader or system administrator and the possibility of easily integrating these rules into the user interface.
- A rigorous validation of user-defined process rules by means of standard XML tools and mechanisms.

3.3 DILAS System Architecture

One of the design goals of the DILAS project was to rely on state-of-the art commercial database technologies. The current system is using an Oracle 9i DBMS. The DILAS system consists of the modules DILAS Server, DILAS Manager, DILAS 3D Modeler and DILAS Scene Generator (Nebiker, 2002b).

3.3.1 DILAS Modules

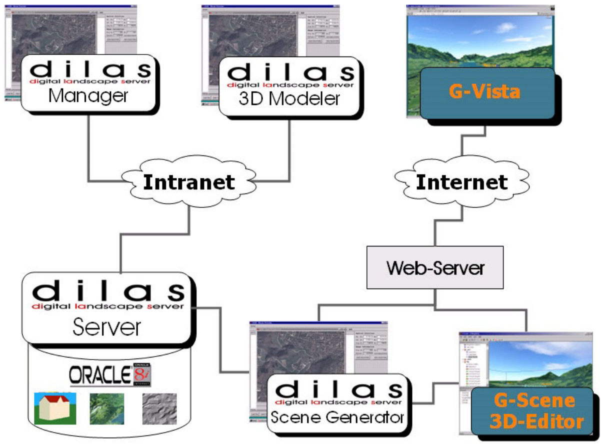

Figure 6: DILAS System Architecture

The Server and Manager modules make up the core components of the system. They address the aspects of storage management, 3D scene management and querying, representation mapping as well as 3D scene export and import.

The 3D Modeler component is built into MicroStation V8, the latest CAD version of Bentley Systems. The 3D Modeler module performs the mapping between the DILAS 3D object model and the MicroStation V8 geometry model. Through the MicroStation Java API DILAS 3D Modeler has full access to the CAD geometry model and to the abundance of construction and import/export functionality available within MicroStation V8. Currently, DILAS 3D Modeler incorporates functionality for the editing of 3D objects, the automatic generation of 3D buildings from roof models or 2D map data and for the interactive texturing of 3D objects.

The DILAS Scene Generator plays a key role in enabling the web-based visualisation of very large landscape and city models using GEONOVA's high-performance 3D-visualisation software G-VISTA. DILAS Scene Generator generates web-based multi-gigabyte 3D scenes with large numbers of 3D objects.

3.3.2 The Integration of 2D and 3D – One of the key factors in making 3D city models and landscape models a technical and commercial success will be the integration of 3D landscape management solutions with existing 2D GIS environments.

In DILAS this 3D-2D integration is achieved by adapting the OGC Simple Feature data model and by extending it with the spatial data types listed in the previous section. This approach yields a number of benefits:

- the vast amounts of existing 2D geodata can also be accessed and exploited in 3D
- the 3D geometry, for example, can be treated as a spatial attribute of a conventional 'GIS feature'
- the 2D representation of a 3D object is visible as a read-only attribute in any OGC SF compliant GIS

3.4 Support for Visualisation and Animation in DILAS

In addition to the broad range of 'standard' GIS functionality, DILAS also provides a number of features, which specifically support or facilitate the visualisation and animation of reality-based 3D models.

3.4.1 Support for 3D Object Appearance – DILAS provides a comprehensive support for 3D object appearance, including colour, transparency and object textures. These appearance attributes can be assigned to any geometric element within the 3D geometry model. All appearance information is stored within the Oracle 9i database.

3.4.2 Semantic Colour Editor – Since all geometric elements of a 3D object may also carry semantic information, e.g. about the type of element (e.g. roof or façade) or the type of material (e.g. glass or aluminium), this attribute information may be used for controlling and editing the object appearance. The DILAS 3D Modeler incorporates a powerful colour editor (Figure 7) which uses spatial and semantic predicates for manipulating colour and transparency of entire city models, of individual 3D objects or specific parts thereof.

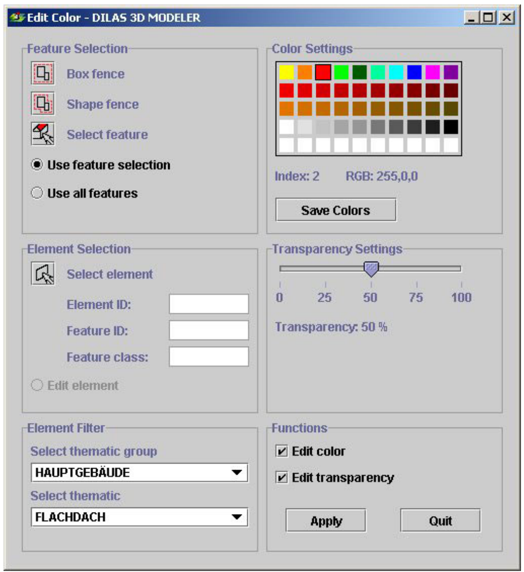

Figure 7: DILAS 3D Modeler – Semantic Colour Editor

3.4.3 Texture Editor – DILAS also incorporates a tool for the assignment and editing of object textures (Figure 8). After selecting one or several 3D objects from the database, images can interactively be assigned to the object geometry. The results of this assignment and the imagery are stored in the database as part of the 3D object model. The texturing process is supported by additional tools for the verification and correction of normal vectors and by an integrated 3D viewer which enables the immediate verification of the texturing results.

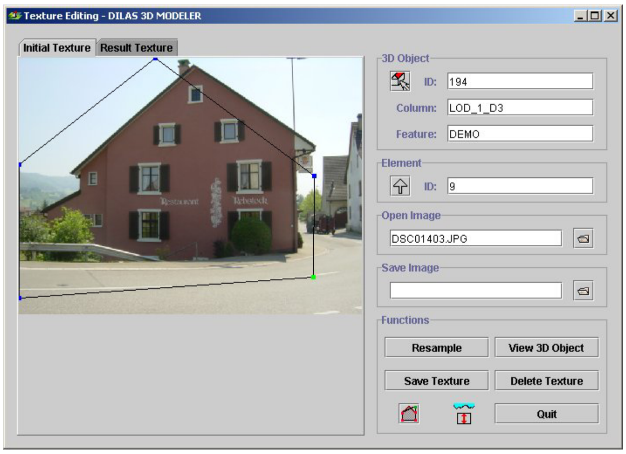

Figure 8: DILAS 3D Modeler – Texture Editor

3.4.4 Other Features Supporting Visualisation and Animation – From a visualisation and animation perspective there are a number of additional interesting features supported by the DILAS / G-VISTA product line. These include:

- *On-demand colour and texture control* during 3D scene generation and export. Among the supported options is a feature- and attribute-based appearance control. With this function colours or transparency can be assigned based on a specific object class (e.g. all railway bridges) or based on certain attributes (e.g. all buildings with flat roofs).
- *Recording of flight paths and integrated video generation* – Among the many animation options supported by GEONOVA's G-VISTA 3D viewer is the possibility to record flight paths and to generate animated videos using these paths.

4. APPLICATIONS AND RESULTS

The following projects and case studies were carried out using the DILAS 3D GIS. They illustrate the potential and benefits of such an integrated 3D geodatabase environment.

4.1.1 3D GIS Case Study "Town Planning" – A recent diploma thesis at FHBB addressed the integration of a 3D GIS into the town planning environment of the city of Rüschlikon in Switzerland. Among the investigated aspects were potential applications, data products, work flows and the 2D-3D GIS integration. As part of the investigations CAD-based building projects were integrated into the 3D GIS. Subsequently a range of 3D products were generated directly from the DILAS system environment including VRML scenes with different appearance options (Figure 9 and Figure 10), hardcopy 3D-prints (Figure 11) and interactive web-based 3D scenes for the G-VISTA viewer environment.

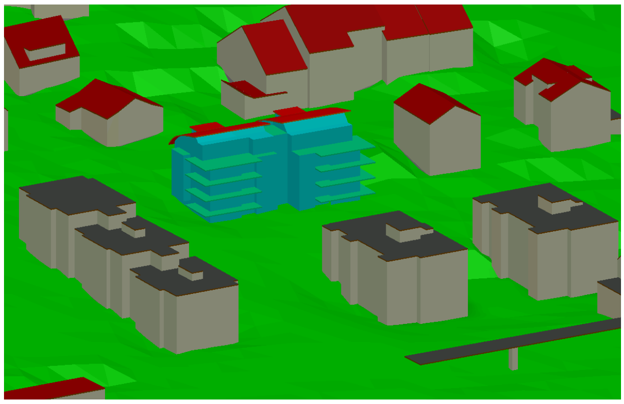

Figure 9: Highlighted construction project with coloured city model

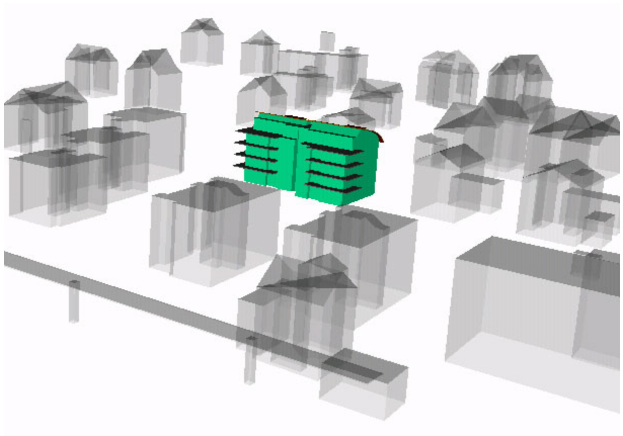

Figure 10: Highlighted construction project with semi-transparent city model

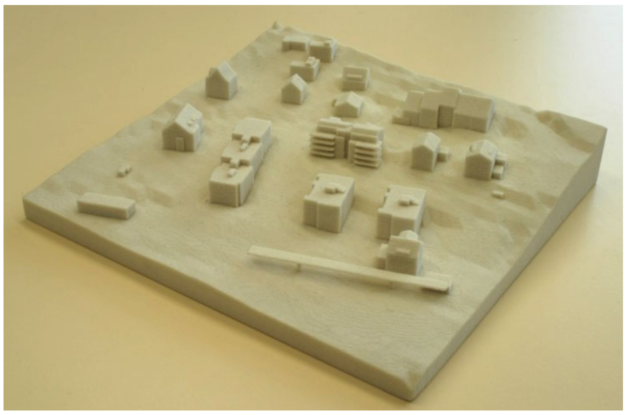

Figure 11: Hardcopy 3D city model of the same area exported from the 3D GIS and produced with a 3D plotter.

4.1.2 Reality-based 3D Geoinformation Services – Reality-based 3D models are playing an increasingly important role in the communication and assessment of infrastructure projects. One of the upcoming major construction projects in Switzerland will be a new railway tunnel crossing the Jura mountains south of Basel. The access route to this new tunnel will lead through densely populated areas and has led to heated political discussions in the past. A large reality-based 3D model of the access corridor with thousands of 3D objects is playing an important role in the current planning and communication strategy. DILAS was chosen as a project platform, also because of the long-term character of the project and the need to gradually refine the 3D model over time. Figure 12 and Figure 13 show small extents of this highly detailed regional 3D scene.

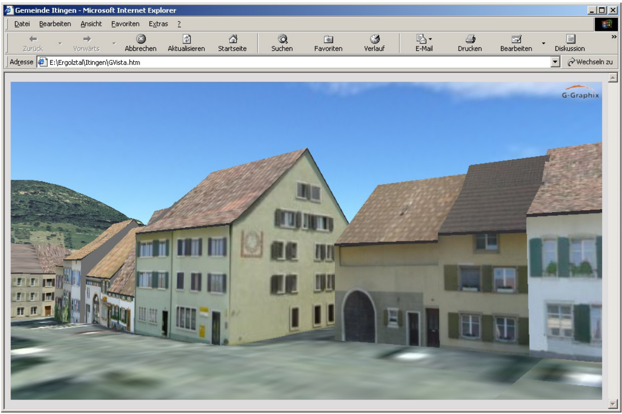

Figure 12: Interactive reality-based 3D model of the town of Itingen in Switzerland (web-based viewer G-VISTA).

Figure 13: 3D model with close-up of highway overpass.

5. CONCLUSIONS

Regional to national 3D landscape models bear a tremendous potential for illustrating spatial phenomenon to professionals and to the general public alike. The author strongly believes that reality-based 3D geoinformation services will play an important role in the emerging mobile information society.

Some of the key factors for the commercial success of such 3D services will be:

- the re-usability and integration of existing 3D geodata
- the integration of 2D and 3D geodata
- the inclusion of semantics
- and a comprehensive support for realism and animations

3D GIS are ideally suited to efficiently address these issues. With the increasing degree of automation and productivity in the acquisition of 3D geometry, the 'production of realism' is rapidly becoming one of the main cost factors.

With the award-winning research project DILAS and the resulting 3D GIS product line, the feasibility and advantages of completely integrating reality-based 3D models into a single geodatabase could be demonstrated. Results from projects with very large 3D city models and web-based national 3D geoinformation services underline the excellent scalability, flexibility and performance of such a 3D GIS environment.

6. ACKNOWLEDGEMENTS

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