17 Real-Time Virtual Landscapes

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17.1 Potentials, Limitations, and Challenges

Real-time virtual landscapes serve as interactive, intuitive tools for exploring, analysing, synthesising, and communicating plans, impressions, and simulations of 3D landscape models. They represent a general form of geovirtual environment (GeoVE) and can be constructed by terrain models, building models, and vegetation models. Due to their generality, real-time virtual landscapes can be applied not only in landscape planning but also to a broad range of applications and systems in the geosciences, such as in environmental information systems, disaster management systems, homeland security applications and facility management systems. They constitute, in a sense, an essential user interface paradigm for geospatial information.

Fundamental limitations result from the *human landscape perception*, which is based on a complex cognitive and aesthetic process. Only through the intellectual processing of what has been seen, the visual information of a landscape model turns into what we call landscape. Hence, the processing and interpretation efforts are high (Zube 1987). The cognitive product “landscape” mainly consists of the factors education, experience, and enjoying observation (contemplation). This connection is well known in the landscape planning profession.

In multimedia cartography, effective means have to be investigated to overcome limitations in landscape visualization. For example, abstract and graphically often insufficient maps, imprecise and manipulative perspective presentations, non-representative still pictures (e.g., montage-based imagery), or high-speed fly-throughs from bird's eye views based on cost-intensive, manually modelled 3D scenes neither convince experts nor non-expert users.

Landscape visualization requires understandable and visually interesting presentations and interfaces. Crucial features systems have to support include:

- Real-time photorealistic rendering for large-scale landscape models;
- Convincing representation of complex, realistic vegetation objects;
- Direct manipulation and editing of landscape objects;
- Seamless integration heterogeneous 2D and 3D geodata; and
- Views at all scales (map views, bird's-eye views and pedestrian views).

In a sense, real-time virtual landscapes translate Repton's idea (Daniels 1999) with his Red Books to draw different planning situations from the viewer's perspective into a new, digital media-based dimension. Fig. 1 gives an example of a real-time virtual landscape, the lost Italian Garden of Sanssouci park, Potsdam.

Fig. 1. Reconstruction of historic gardens and parks by virtual landscapes.

17.2 3D Landscape Models

A virtual landscape represents part of a real or imaginary landscape by a landscape model, which is composed in a hierarchical way based on landscape objects. They include the digital terrain model (DTM), 2D imagery data such as aerial photography or topographic maps, 2D planning data such as cadastre data or street networks, 3D building data, and 3D biotope and vegetation data. The landscape model is complemented by georeferenced thematic data relevant to the application domain (e.g., land use data, contamination data, or socio-demographic data) and by meta visualization objects (e.g., annotations, legends, compass and virtual sky).

Landscape objects do not only define attribute data but also functionality represented by their methods. For example, a building object has attributes such as ground polygon, height, roof type, number of floors etc. but it also provides the functionality to construct the roof geometry according to the roof type, the walls according to the building height and ground polygon, and it can calculate building-specific properties such as the number of square meters available or its volume. In particular, object-oriented modelling of vegetation objects has been one of the major innovations required for convincing real-time virtual landscapes. For example, an alley should be represented as a group of trees, placed parallel along a street with defined distances apart. If the course of the street, the distance, or the tree type is changed the alley automatically should re-instantiate its components. In this way, built-in functionality becomes directly available to the landscape modeller and provides higher-level functionality compared to purely virtual reality systems.

17.3 Functionality of Real-Time Virtual Landscape Systems

From a technical point of view, a real-time virtual landscape system is characterized by the following functionality and properties:

- *Real-Time Rendering* – allows us to interactively operate, explore, and analyze landscape models;
- *Vegetation Modeling* – need to be detailed, three-dimensional, and botanically accurate to be convincing and useful landscape objects;
- *Vegetation Arrangement* – includes the instantiation, distribution, orientation, of plant models according to characteristics of plant species, soil type, topography and other relevant parameters;
- *Landscape Editing* – required to directly edit and manipulate landscape model objects without having to switch between a 2D conceptual, map-based view and a virtual reality 3D view;
- *Landscape Interaction* – requires navigation tools and support for orientation in the 3D geovirtual environment, in particular, the user should be able to select between different navigation tools such as walking and flying;

- *Scalability* – the rendering techniques used should be able to process massive data sets, which typically occur even for small virtual landscapes (e.g., aerial photography of 300 GB for a middle-size town in a resolution of 20 cm), using multi-resolution algorithms and data structures; and
- *Interoperability* – requires that geodata can be exchanged in standardized formats. For 3D geodata, e.g., for building models and vegetation models, there are still no standards available but XML-based first approaches exist (e.g., CityGML (Kolbe et al. 2005)).

17.3.1 General System Architecture

The architecture of real-time virtual landscape systems typically consists of two core components, the authoring and presentation systems. In the following, this refers to the *LandXplorer* system, a real-time virtual landscape system outlined in Fig. 2.

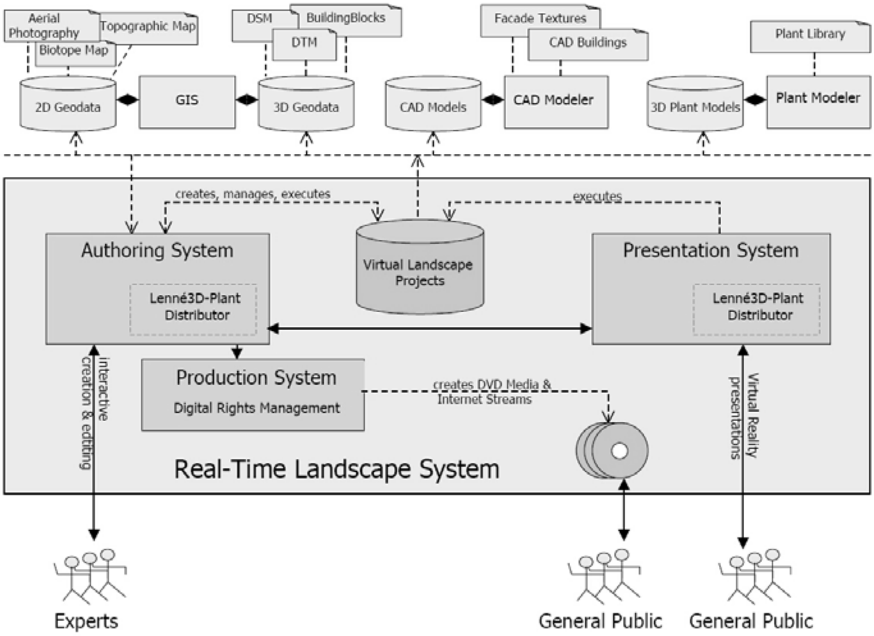

Fig. 2. General architecture of a real-time virtual landscape visualization system (Image: 3D Geo/LandXplorer).

The *authoring system* is responsible for creating, managing, and storing the virtual landscape model and the specification of its presentations. It provides the user interface for the real-time landscape system.

The *presentation system* is responsible for real-time rendering of complex landscape models. It can be used within the editor, also as a standalone application. It provides optimized rendering techniques for presenting large-scale landscapes.

Both components rely on the *plant distribution subsystem*, supporting instantiating, placing and configuring vegetation objects. Since plant distributions are determined on-demand, authoring and presentation systems require its services.

The *production system* is responsible for exporting virtual landscape projects to different distribution media, whereby geodata has to be selected, resampled, serialized, compressed and encrypted. *Digital rights management* (DRM) mechanisms need to be included as well, which protect the digital contents of virtual landscapes and, thereby, provide means to control the usage and distribution of virtual landscapes. DRM is a prerequisite for using virtual landscapes for different target user groups to comply with license and usage rights. For example, the production system can encapsulating a virtual landscape into a black-box, executable software unit distributed on DVD.

17.4 Building Blocks of Virtual Landscapes

The authoring system serves as tool for constructing and designing virtual landscapes offering three categories of building blocks:

- *Geometry objects* represent geodata and geo-objects, including multi--resolution 3D terrain models, 3D building models, and 2D raster data;
- *Behavior objects* specify interaction and animation capabilities available to geovirtual environments, including animated camera bookmarks or dynamic textures; and
- *Structure objects* hierarchically organize the components of a geovirtual environment, including component groups and information layers.

Collections of building blocks are arranged in information layers. *Raster-data layers* represent rasterised 2D geodata such as aerial photography, topographic maps or terrain shadings. They are positioned on top of the digital terrain surface according to their geo-coordinates. Each layer can have a different resolution and extension and it can overlap with other layers.

Vector-data layers represent both 2D vector-based graphics (e.g., georeferenced points, lines, polygons and curves) as well as 3D vector-based graphics (e.g., 3D buildings and 3D vegetation groups). Each object contained in a vector-data layer can be identified and directly edited in the 3D view.

2D raster and vector information layers are projected onto the terrain surface and can be combined by defining the imaging operation applied to corresponding textures during rendering, e.g., weighted addition or modulation (Döllner *et al.,* 2000). For example, aerial photography (raster data) can be visually combined with a street network (vector data) on-the-fly (Kersting and Döllner, 2002).

17.5 3D Building Modeling

Building models are fundamental objects from which virtual landscapes are composed, although they are sometimes not the dominant elements in terms of quantity. Four general *levels of detail* are distinguished according to CityGML, a proposed standard for virtual city models (Kolbe *et al.*, 2005):

LOD 1: Box models based on 2D polygonal ground planes with associated heights - representing the simplest type of building, suitable in the initial phase of creating virtual landscapes;

LOD 2: Building models with detail facade geometry and roofs, useful in particular to model far-away buildings such as those in the surroundings - level 1 and 2 buildings can be generated mostly in an automated way, which makes them suitable for large-scale virtual landscapes;

LOD 3: Building models with detailed textures and architectural elements - manual modeling or an automated transformation of CAD models (e.g., ArchiCAD, IFC) are required; and

LOD 4: Architectural building models with interior designs. For virtual landscapes indoor models are of less importance.

To enable real-time rendering of large-scale landscape models, their complexity has to be reduced in order to guarantee high and constant frame rates. For virtual environments, geometry or texture related optimization algorithms are available, e.g., automatic impostor placements (Jeschke, 2005), multi-resolution facade texture atlases (Buchholz and Döllner 2005), or approximating scenes by billboard clouds (Decoret, 2003).

17.6 3D Vegetation Modeling

P*lant modelling*, that is, modelling individual plant types (e.g., an 100-year old oak tree) can be distinguished from *vegetation modelling*, that is, modelling a setting of plant objects in a specific area (e.g., a forest of oak trees).

17.6.1 3D Plant Modeling

Plant modelling represents a challenging task, particularly because botanical knowledge is required and manual processes are involved, for example, to collect images of plant parts, to scan leaf textures, to produce variants of a single plant, and to set up properties for a plant type. Although plants appear in countless computer graphics works, a botanical-based, three-dimensional approach to plant modelling is still an active research area.

Each plant model is defined by its 3D geometry and a collection of textures (frequently captured from real plant parts) used to achieve a high degree of photorealism. Specialised 3D plant modelling systems are available such as *xfrog* (greenworks organic software) and *bionatics*. The *xfrog* plant modeller offers object-oriented building blocks such as nodes for leafs, branches, arrangements, curves, and variations (Deussen, 1998). Based on hierarchical graph-based plant specifications, the resulting 3D geometry of a single plant can be derived.

For the *LandXplorer* system, the Lenné3D library (Paar 2003) is employed. It contains detailed plant models for more than 500 plant species that occur in Europe. For each plant species its state in spring and winter as well as variants for different growth states are provided.

17.6.2 3D Vegetation Modeling

Vegetation modelling is broken down into two stages (Röhricht 2005). In the first stage, pedological maps and/or relief data (e.g., altitude, exposition, slope) or other expert data are combined with vegetation referenced spatial data (e.g., maps of biotope types) to produce more or less homogeneous parts (so-called geo cells) in the landscape. These clippings will then be combined with *relevé* data at the next stage. The dispersion of every plant within the corresponding geo cell is automatically computed, based on the sociability of the particular species or on a manually specified distribution path. Depending on the size of the sample area, hundreds of thousands, up to several billions of single plant individuals can result (Fig. 3), whose locations must be provided to the rendering system.

In the *LandXplorer* system, vegetation modelling is based on specialized information layers, the *vegetation layers*, which contain biotope and land use data together with additional GIS thematic data such as topographic data, history, and soil type information. Based on vegetation reference tables, the plant distributor subsystem calculates the plant distribution for a given area, and it assigns plant models to these distributions. A vegetation layer can also contain explicitly placed and instantiated objects, for example landmark-like trees.

Fig. 3. Example of a vegetation group with a large number of plant instances (Image: Lenné3D).

The plant distributor determines the contents and spatial distribution of vegetation layers by heuristic-algorithmic techniques. The distributor also takes into account additional spatial information such as terrain slope, terrain exposition, or land use type. For example, an area of bushes can be specified by the area polygon, the density in which bushes should occur, and the distribution function, which could specify an exposition range that constrains possible locations for a single bush.

17.7 Real-Time Landscape Rendering Techniques

In general, rendering for complex virtual landscapes is based on real-time, multi-resolution rendering algorithms for 3D scene geometry (Akenine-Möller and Haines 2002). Landscape rendering, in particular, has to cope with two core requirements, 1) handling large-scale terrains and related textures and 2) handling up to millions of individual vegetation objects. Multi-textured, multi-resolution terrain texturing algorithms together with out-of-core level-of-detail algorithms (i.e., algorithms optimized for externally stored, large-scale data) provide efficient solutions. For example, the multi-resolution texturing technique (Döllner *et al.* 2000) operates on virtually unlimited raster data sets; and the virtual landscapes used up to 300 GB of terrain texture data in real-time.

Vegetation rendering is faced with two core challenges: 1) Complex geometry – a single plant model, say a typical tree, commonly contains between 50,000 and 150,000 textured triangles, whereby large parts are spent on leaves. 2) High quality – the human experience in seeing plants is highly developed. Therefore, observers are critical with respect to “fake plants” constructed with billboards, which may be suitable for distant rendering of plants, but do not allow rendering of convincing, detailed trees from a close perspective.

Specialized level-of-detail rendering techniques (Coconu and Hege 2003) are required, e.g. by point-based and line-based simplification schemata. Roughly speaking, only vegetation objects directly in front of the camera are rendered with full detail, whereas all other vegetation objects are approximated by 3D points, 3D lines, or 3D billboard clouds that resemble the overall geometry of the tree. Consequently, virtual landscapes with a high amount of photorealism become possible. To further optimize the scene geometry, the vegetation layers can decide whether to instantiate individual plant objects or to use approximations. For example, once the observer comes close to a lawn area, say up to 20 cm, the individual blades of grass close to the observer are instantiated, in all other cases the lawn area is approximated by simplified geometry and treated as a whole.

17.8 Navigating Through Virtual Landscapes

Navigation is a key factor for user acceptance of real-time virtual landscapes typically suffering from the lack of a proper handling and prevention of confusing or disorientating situations. As Fuhrmann and MacEachren (2001, p. 1) point out, “core problems for users of these desktop GeoVEs are to navigate through, and remain oriented in, the display space and to relate that display space to the geographic space it depicts."

Local navigation controls are anchored by spatial positions such as defined by the center of the visible part of the landscape. The spherical trackball, for example, simulates rotating a virtual sphere enclosing that visible area. Similarly, the conical trackball supports zooming within the virtual cone. In addition, the walking mode, commonly known from computer games, represents an avatar walking in the virtual landscape and provides a pedestrian's perspective. As a characteristic element of local navigation, only part of the geovirtual environment is visible, and the camera remains close to anchored objects of the virtual landscape.

Global navigation controls aim at providing a spatial overview and allow for browsing and selecting local areas. In general, the distance between camera and virtual landscape is much larger compared to local navigation techniques. Well-known metaphors include, for example, flying vehicles such as virtual airplane and the virtual helicopter.

Smart navigation controls (Buchholz *et al.*, 2005) help to solve this situation giving user guidance: they interpret user interaction regarding the current view specification, i.e., the parameters of the virtual camera, and determine if the user is about to get into confusing or disorienting situations in an anticipatory way. They guide the user away from situations where usual navigation behaviour tends to fail and they always indicate to the user when the guidance mechanism is operating, so that the user understands the behaviour of the smart navigation strategy. Smart navigation strategies are useful to inexperienced users reducing the need for specific training.

Technically, smart navigation splits common navigation techniques into two steps: 1) The mapping from user interaction events to camera movements takes place; and, 2) the intended movement is checked against several constraints and modified if necessary. Smart navigation controls are composed by interaction constraints (Döllner, 2005) such as:

Spatial constraints: Restrict spatial parameters of GeoVEs such as camera position, orientation, and movement;

Structural constraints: Restrict operations that modify GeoVE components, such as replacing or adding components; and

Redistribution constraints: Define the properties of distributed GeoVEs.

17.9 Case Study: The Lost Italian Gardens

Since May 2002, the joint research project Lenné3D (Paar, 2003) has developed a system for real-time 3D landscape visualization both from map view and from stroller's view. The Lenné3D system is targeted on supporting the dialogue on community landscape planning and decision-making. One core case studies represents the "Italian cultural showpiece", a jewel of the Potsdam-Berlin (Germany) park and garden landscape, which was largely arranged by Peter Joseph Lenné (1789–1866) two centuries ago, and was designated part of the UNESCO world cultural heritage. The garden was laid out in 1834 to the west of the Roman Baths in Sanssouci park to complete the atmosphere of an Italian country villa as created by the Roman baths (Fig. 4) Grape vines and pumpkins once grew like garlands scalloping between elm and mulberry trees, between ornamental and useful plants from the Mediterranean, thus emphasizing the agricultural character of the Roman Baths. Many of the plants used are not winter-hardy in central Europe, their cultivation is demanding and their care is very labor intensive. Within only 50 years after its creation nothing remained of the garden.

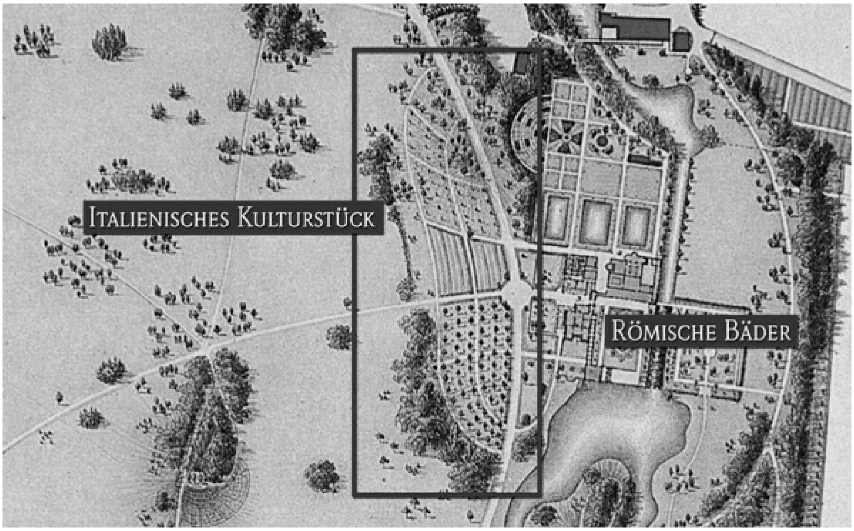

Fig. 4. The historic map of the Italian Garden. (Image: Lenné3D)

Landscape planners, officials, and the general public are recently discussing how to reconstruct the lost garden in the long term. To study and understand its structure, composition, and appearance as well as to provide experts and the general public with an impression of the former diversity of the horticultural garden a real-time virtual landscape was created. In summer 2004, more than 20,000 people visited the exhibition “Prussian Green” where the virtually reconstructed Garden of the 19th century was presented to the public within a virtual reality environment using a concave 180° panorama screen (Fig. 5). By means of a tangible interface, a light wheel illuminating the viewer’s location and viewing direction on a table surface, the visitor, standing in the half circle of the screen, was able to choose his own path through the garden in an intuitive manner and thus immerse himself/herself in the virtual world.

Fig. 5. Panoramic screen used by a real-time landscape of the lost Italian Garden.

17.10 Conclusions

Virtual landscapes rely on an integrated modelling of 3D buildings, 3D vegetation and 3D terrains. Their inherent geometric complexity requires specialized multi-resolution and rendering algorithms. Beside the technical challenges, a subtle, possibly unconscious criterion for user acceptance must be met, that of the visual quality of vegetation presentations. The landscape models also serve to integrate heterogeneous 2D and 3D geodata, in a uniform, broad conceptual frame. This way, real-time virtual landscapes have a high potential for becoming essential geovirtual environment types in multimedia cartography.

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