ELSEVIER

Landscape and Urban Planning 54 (2001) 163–182

LANDSCAPE
AND
URBAN PLANNING

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The limits of realism: perceptions of virtual landscapes

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Received 4 January 2000; received in revised form 27 April 2000; accepted 4 June 2000

Abstract

Communicating planning results within expert groups or to local citizens is crucial to an efficient planning process. In the planning and design disciplines such as landscape and urban planning, recent digital 3D-visualizations have gained increased recognition. However, the validation of simulations of virtual landscapes, in terms of their degree of realism (R'Degree) has so far been neglected in research. This study concentrates on the question whether, how, and to which degree the real visually perceived landscape, represented through photographs, can be validly represented by means of virtual landscapes. The study area comprises the communities of Schwyz and Ingenbohl–Brunnen situated on Lake Lucerne in Central Switzerland.

From a modelling point of view, landscapes are highly complex structures. Instead of manually modelling the virtual environment, which is the traditional CAD-approach, a GIS-based approach is pursued. This is the prerequisite for the efficient visualization of large data sets.

The validity of the created virtual landscape is tested in an empirical study in which test persons are asked to order a set of real images and variations of the corresponding computer-generated images. In the experiment, approximately 75% of the test persons assigned the highest possible value (very high degree of realism) to one or more scenes of simulated landscapes. In order to achieve an even higher degree of realism, more and very detailed 3D-object-data and accompanying texture information would be necessary.

Keywords: Landscape visualization; GIS; Virtual landscapes; Perception; Degree of realism

1. Introduction to the visualization of the environment

This paper describes research undertaken as part of a Ph.D. thesis concentrating on the visualization and perception of virtual landscapes.

Until recently spatially relevant disciplines such as urban planning or landscape planning were facing the dilemma of how to work in two dimensions without having an adequate instrument for the representation of the third dimension. Up to now this has had the consequence that, in principle, planning is predominately carried out in two dimensions — i.e. a building becomes a black rectangle, a tree becomes a green circle and terrain is reduced to a set of contour lines.

However, there exist a number of well-known analog as well as digital visual simulation techniques for the representation of the environment. These visualizations are typically only very loosely integrated in the planning process, thought of as a sometimes expensive supplement to sell the final planning product. The reason for this is the missing connection between the planning action itself and the data utilized and the type of representation of the result of the planning process.

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PII: S0169-2046(01)00134-7

The techniques for the visual simulation of the environment can be classified as stationary/static or dynamic simulations (McKechnie, 1977) and analog or digital.

Static simulations like retouched photographs show a site as seen by a static observer. Dynamic simulations (which can also be static images as part of an animated sequence) like computer animations, show it as seen by a moving observer. This has the great advantage, that the observer is not limited to certain predetermined viewpoints. Instead the observer can move around freely, depending on the size of the digital model perhaps even in real-time.

1.1. Analog visualization techniques

The classic analog visualization tools for the representation of ideas in planning and design are plans, sections, sketches, perspective drawings, photomontages, and physical models. Although having being invented around 465 BC in Greece (Geyer, 1994), it took several hundred years for the perspective to be re-invented in the renaissance and to become a common tool in architecture for the presentation of the final design.

Among landscape architects Repton (1803) can be seen as an early pioneer in visualization. In his Red Books Humphry Repton concentrates on the representation of proposed changes in the landscape in perspective view comparing the existing situation with his proposal.

A fairly common technique for representing a proposal is the photomontage. As a direct consequence of the technological development, the analog photomontage is now being superseded by the digital photomontage (e.g. Lange, 1990). Unlike the traditional analog photomontage, a digital photomontage can reach a relatively high level of geometric accuracy. This can be achieved by superimposing 3D-vector data over the 2D-image data (see, e.g. Lange, 1994; Shang, 1992).

Among the analog techniques, only the physical model permits the free eye movement of the observer. By using a modelscope, models even allow to be visited at eye level. The use of physical models like in the Berkeley Simulation Laboratory (see Appleyard, 1977) was relatively popular in the early 1970s and 1980s.

1.2. Digital visualization techniques

Within the last few years relatively sophisticated technological innovations allowing work in three-dimensions have been introduced.

The basic elements of the landscape which need to be represented for planning purposes are terrain, built objects and vegetation. Like terrain data image data is a common data source being used at various resolutions. The actual land use information can be represented through imagery acquired through remote sensing. The sensors providing satellite imagery are constantly improving (an overview is provided by Sheffner and Stoney, 1999). For example, the new Ikonos sensor launched in September 1999 captures images with a resolution of 4 m in the visible and near infrared range.

Typically integrating built objects in a virtual environment is a very labor-intensive process. A new efficient approach to record existing built-objects is based on a semi-automated generation of 3D-objects of the built environment, which allows the fitting of planar structures to a measured set of point clouds (Gruen and Wang, 1999).

Like buildings, the vegetation is also typically modelled as a combination of polygonal surfaces. The problem with this approach is that even one single tree with leaves or needles can consist of thousands of polygons. Consequently this has a considerable impact on rendering time. Instead of manually modelling a tree or relying on an exisiting object library, another, also polygon-based approach was developed by Prusinkiewicz and Lindenmayer (1996). Their L-system which allows the rendering of photorealistic plants is based on a formal language describing the natural growth of the plants. What so far has not been realized, but which might be possible to do, is the photogrammetric measurement of vegetation. However, this would cause the problem of replacing a highly complex structure such as a tree by an enormous number of polygons (“so many polygons, so little time”).

The most efficient method to display vegetation structures is texture mapping. By using texture mapping, complex 3D-geometries and microstructures of object surfaces can be replaced by relatively simple texture maps like the image of a tree consisting of 256×256 pixels, which can be applied on polygonal surfaces. This allows a high visual complexity of a scene without having to increase the geometric complexity.

2. Perception of simulated landscapes

2.1. Reality and simulation

A simulation, today mostly in digital format, is always a more or less abstracted version of the complex reality. Mandelbrot (1983, p. 1) characterizes this fundamental problem of the digital representation of natural phenomena as follows: "Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line". A similar opinion is expressed by Foley et al. (1990, p. 607): "A fundamental difficulty in achieving total visual realism is the complexity of the real world. Observe the richness of your environment. There are many surface textures, subtle color gradations, shadows, reflections, and slight irregularities in the surrounding objects. Think of patterns on wrinkled cloth, the texture of skin, tousled hair, scuff marks on the floor and chipped paint on the wall. These all combine to 'real' visual experience".

On the other hand, it can be argued that even simulations with a lower degree of realism can still contain the most important information needed for a specific purpose. Representations used in flight simulation have to have an overall realistic impression without having to contain detailed landscape features. Most important for these kinds of applications are factors like functionality and interactivity and having the ability to display, e.g. potential obstacles which could be of importance during the landing procedure. Consequently, Appleyard (1977, p. 58) addresses the problem less from a technical side but stresses the influence of variation in the individual perception: "When one talks of realistic simulations, the questions arises: which reality or whose reality are we trying to reproduce?". He proposes two methods to be pursued in order to determine the degree of realism (Appleyard (1977, p. 65 and 66): "The comparison of responses to simulations with responses of equivalent groups to real situations is the ultimate test of realism". Alternatively, he suggests that "An analysis of media images can be a helpful and cheap method of gaining a general idea of media realism. The degree to which a medium can create a visual replication of real-world scenes through its detail, texture, tone, color, view field, viewpoints, three-dimensionality, movement, and sound is a test of its realism".

A comprehensive definition of the term 'realistic' is given by Hall (1990, p. 191): "Creating an experience that is indistinguishable from the real experience; generating the same stimulus as the real environment; generating the same perceptual response as a real scene; creating the impression of a real scene". Realism is determined by the following key elements (Hall, 1990, p. 195): "The impression of realism does not necessarily require correct imagery in terms of geometric detail as long as the general behavior is reasonable; that high image complexity is primary in creating the perception of realism; that subtle shading and surface detail are key in creating the perception of realism".

2.2. Empirical perception research on landscape representation

Applications of digital visual simulation techniques have become wide spread in the recent years. Already Appleyard (1977) pointed out the problem of a missing theoretical background in regard to the perception of real and simulated scenes of the environment. Systematic research in this field is still rare and fragmentary (see Hetherington, 1991).

Since the 1970s and 1980s, studies have been conducted which deal with photography as a surrogate of the real landscape (e.g. Dunn, 1976; Trent et al., 1987; Stamps, 1993). The conclusion is that color photographs are valid representations for judgments about the visual environment. The same is true for scanned photography from a video source (Vining and Orland, 1989). Watzek and Ellsworth (1994) could even prove that test persons were not able to recognize geometric differences of up to 15% artificially made through digital photomontage techniques.

McKechnie (1977), Bosselmann and Craik (1987) and Schwanzer (1987) studied the representational quality of physical urban and architectural models versus the real environment. In all three cases, the physical models were seen as good representations of the real environment. However, Schwanzer (1987) reports differences in assigning adjectives.

Killeen and Buhyoff (1983) compared preference for very rudimentary sketches and computer graphics with photographs. Their results indicate that the preference metrics for 35 mm slides and the computer line drawings were significantly correlated with the preference metric for the artist renditions. However, no association was found between preference for the slides and the computer-generated drawings (p. 381).

The research of Tips and Savasdisara (1986) concentrated on different levels of abstraction by using computer-generated line drawings. The level of abstraction had a significant influence on the ranking of representations of landscapes. In accordance with Killeen and Buhyoff (1983), the authors conclude that there is a definite limit in using abstractions as a basis for measuring preference.

A very sophisticated experiment, in terms of applied technology, was conducted by Meyer et al. (1986). The authors compared a simple physical model (cornell cube) with a computer graphics model using the radiosity method. Both scenes were shown to the test persons via a color television screen. The experiment indicated that the subjects could not distinguish between the physical model and the simulation.

Oh (1994) studied the perceptual response of three photographs of the same building compared with four types of computer simulations: wire frame, surface model, combination of surface model images with scanned photographic images and image processing. Knowing the results of Killeen and Buhyoff (1983), it is not surprising that wire frame models were least effective in representing the environment, whereas image processing simulations were most effective in portraying reality. In terms of 'confidence' in the simulations, the wireframe representations received a mean score of 2.301 on a five point scale. The surface model scored 3.1250, which is very close to the score for the combination of surface model images with scanned photographic images (3.2396). Only those representations where image processing techniques were applied (4.3229) came close to the site images (4.9271).

The only piece of research so far which has tried to study the validity of large computer-generated landscapes was performed by Bergen et al. (1995). They conducted a public preference survey to compare eight pairs of photographs of forest landscapes and computer-generated images. The elements used in their computer model are terrain as shaded relief and forests with trees in a simple or more detailed geometry. They conclude that on the whole the computer-generated landscapes were not good representations of the actual photographs. The authors state that "observer feedback indicates that the lack of correlation is due to the omission of important landscape elements" in the computer-generated images (p. 135), i.e. missing objects in the foreground or differences in variety and texture. A methodological problem inherent in the set-up of the experiment is that not only atmospheric conditions in the image pairs were often completely different, but also the viewing angle of the actual scenes was not matched properly. Therefore, some pairs are differing a lot from each other in terms of the geographical extent of what is shown.

In a current project led by the University of Arizona, Department of Psychology, a highly realistic virtual forest containing approximately 1600 trees and covering 66,000 m^2 is created (House et al., 1998). The purpose of the project is to determine what level of realism is necessary in computer-generated visualizations or animations of natural scenes in order to elicit a human response similar to a response which would be caused by experiencing the actual site. The experiment to be conducted consists of an actual on-site walkthrough, a video of a walkthrough, and computer simulated walkthroughs at two levels of realism (a highly realistic animation, and a more schematic real-time presentation). The study has not been completed yet.

3. Method

3.1. Visualizing the third-dimension: synthesis and abstraction

Within the last few years, relatively sophisticated technological innovations allowing to work in three dimensions have been introduced. In the presented case of the Brunnen/Schwyz region of Central Switzerland instead of manually modelling the virtual environment, which is the traditional CAD-approach, a GIS-based approach is pursued (see Hoinkes and Lange, 1995). This is the prerequisite for the efficient visualization of large data sets, which are needed in landscape visualization. The simulated abstraction of the real landscape mostly relies on data which is either already available or on future publicly accessible 2D data which can be made available through largely automatic procedures.

For the digital visual simulation, a virtual model of the study area consisting of various elements such as a digital terrain model, digital imagery and various kinds of land use data is assembled. The elements forests, single trees and buildings are mostly derived from the digital topographic map 1:25,000.

The terrain is visualized through the DHM25 terrain model of the Swiss Federal Office for Topography. It is an elevation model based on a 25 m grid derived from the 1:25,000 topographic map. The site covers an area of 35 km × 24 km with 1400 grid × 960 grid cells.

In order to simulate a landscape with texture information, digital imagery can be draped over the terrain. The satellite image used is a LANDSAT TM scene at 25 m resolution, resampled from 30 m. For the main parts of the site covering an area of 10 km × 9.8 km, a digital orthophoto was also available. It has the advantage of higher resolution and level of detail. Although imagery is available with a theoretical resolution of up to 0.625 m, for reasons of practicality, i.e. computing time, a lower resolution of 2.5 m is chosen.

The representation of the vegetation is based on the analysis of the digital topographic map of the Federal Office for Topography. This so-called ‘Pixelmap’ has a resolution of 1.25 m at a scale of 1:25,000. Using pattern recognition techniques 2D information from digital topographic maps such as points or circles symbolizing different kinds of vegetation cover can be extracted automatically (Nebiker and Carosio, 1995; Stengele, 1995). The applied procedure was developed and carried out by the Institute for Geodesy and Photogrammetry at ETHZ. Based on the same technique, the Federal Office for Topography is currently producing vector data covering the whole of Switzerland, thereby providing the necessary data base for the general public in the near future.

The resulting 2D vegetation data sets are handled by the GIS-system ARC/INFO. They can be transformed into the 3D environment by setting them on the terrain surface and creating polygonal objects on which the appropriate tree textures from a pre-defined texture library can be mapped (Hoinkes and Lange, 1995; Lange, 1999a). This procedure relies on Polytrim software which is developed at the Centre for Landscape Research at the University of Toronto (see Danahy and Hoinkes, 1995).

Additionally, the footprints of the buildings can be exported from the GIS to the visualization system, in order to create building volumes based on predefined attributes (height of the building). For the detailed representation of built-form, texture-mapping is used in the foreground. However, for this step, manual modelling is required.

The planning disciplines are working with abstracted representations of reality. Nowadays, the key element of this abstraction are digital data. In analogy to a topographic map which is a 2D-representation of the real world (i.e. the orthophoto on which the cartographic interpretation is based on), a virtual landscape is a 3D-representation of the real world, in this example partly based on the information contained in the topographic map (Fig. 1). This has several implications.

Due to the resolution of the terrain model (25 m), a slight variation of the terrain within two sample points such as a small creek cannot be represented. Data from remote sensing platforms can have geometric distortions and radiometric inconsistencies. The horizontal distortion in an orthoprojected image is negligible. However, when draping imagery over terrain, on steep slopes one single pixel can be stretched with a certain factor depending on the gradient of the grid cell.

In an orthophoto-mosaic consisting of several aerial photographs, such as in the presented example, it is important that all original images are taken approximately at the same time of the day. Using aerials from different seasons will cause phenological differences in the coloration of the vegetation.

Using maps is an elegant and efficient way to retrieve a lot of topographical pre-interpreted information in a relatively short time. However, maps and also aerial photography always represent a certain time in the past. In the case of the Swiss topographic map, the production cycle is approximately 6–7 years. Therefore, changes occurring within this period are not captured. Due to map interpretation and generalization, not all elements which are visible on an aerial photograph are represented; also the lettering in the maps is a cause for the omission of certain elements of the landscape. According to Hake and Grünreich

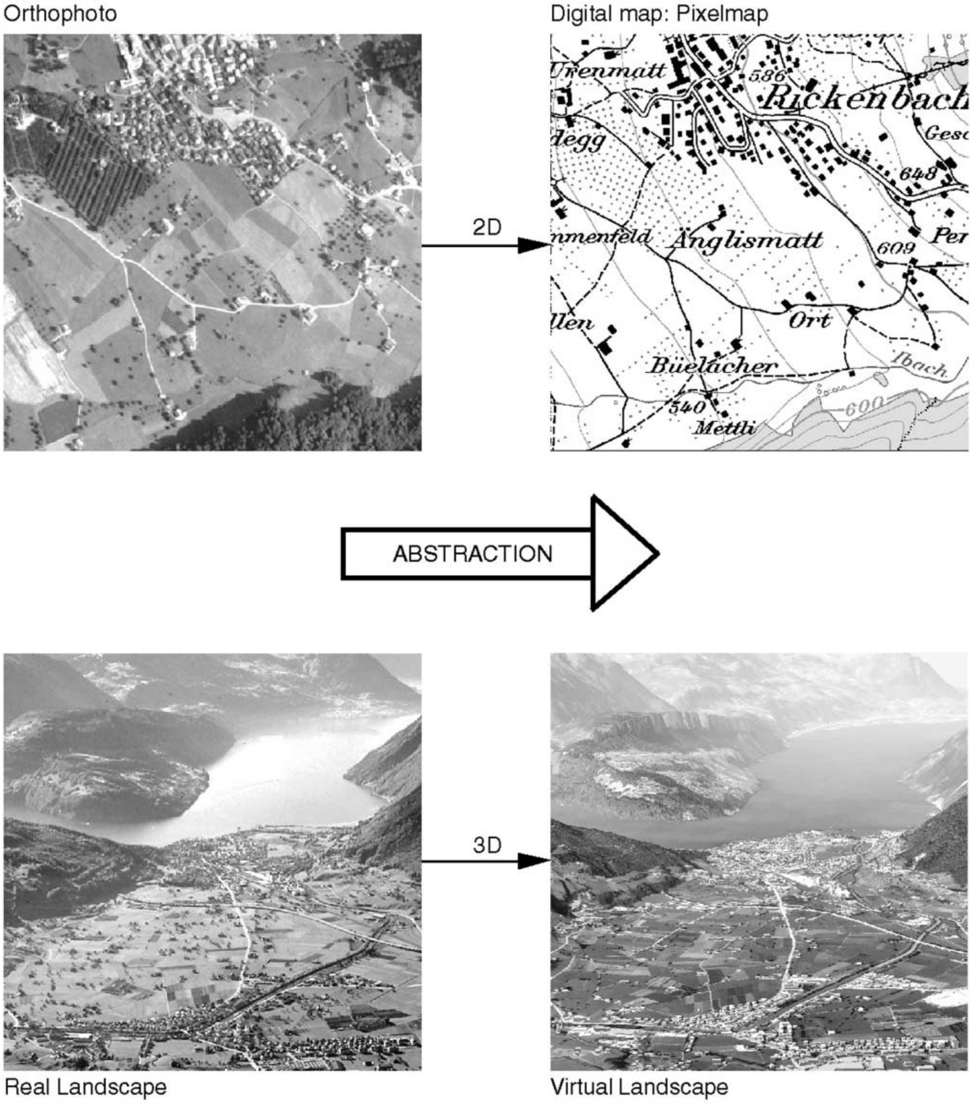

Fig. 1. Abstraction in 2D and 3D.

(1994) in maps up to a scale of 1:25,000, the shape and the number of buildings are represented with a very high degree of precision. This means that on the Swiss topographic maps 95% of the buildings within dense settlement patterns are captured and outside even 100% (SGK, 1975). For the test site, 98.4% of the buildings and more than 95% of the tree symbols can be extracted with template matching (Stengele, 1995).

On the Swiss topographic map at 1:25,000, vegetation is symbolized by points or circles ranging in size between 0.1 and 0.6 mm according to the following nine classes: forest, open forest, bushes, single trees, hedgerows, chestnut trees, orchards/fruit trees, nurseries and vineyards. Without a detailed analysis based either on aerial photography interpretation or by directly mapping the vegetation on the ground, it cannot be determined what is actually there, e.g. whether in reality there is a pear tree or an apple tree growing. The same convention of generalising the actual vegetation into representative classes applies

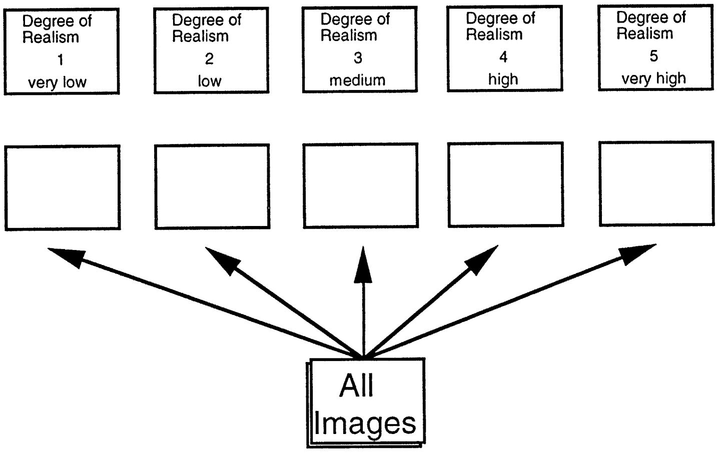

Fig. 2. Test procedure.

to the 3D-visualization of the data. Therefore, each of the classes distinguished in the topographic map can be displayed with different tree textures in the virtual model. In using the dominant element of each of the classes, e.g. displaying an apple tree if 70% of the fruit trees are apple trees, a relatively close approximation can be achieved.

3.2. Experiment: photographic reality and simulation

The validation of visualizations is an essential requirement in order to be able to use visualizations as a basis for the evaluation of possible changes in the landscape. Ideally, both the visualization of a virtual landscape and the real landscape should be rated in a similar pattern compared with each other.

In order to determine the degree of realism of the created virtual landscape, an empirical study was conducted, concentrating on the question to what degree the real visually perceived landscape, represented through photographs, can be validly represented by means of virtual landscapes (Lange, 1999b).

Using scaling techniques, test persons were asked to order a set of sample images which varied in detail, according to the degree of realism on a scale ranging from 1 to 5 (verbally categorized as ranging from very low to very high).

The combination of the elements used in the simulation define through their presence or absence the variation in the virtual landscape used as sample images in the test (Fig. 2, Table 1).

The whole test set consisted of 90 images depicting the virtual landscape of Brunnen/Schwyz as seen from three different viewpoints. Three images were photographs from the three different viewpoints (a background-scene, a middleground-scene and a foreground-scene). Another 86 images were corresponding computer-generated images with different representation levels (e.g. Figs. 4–6). One image is a composite of photo foreground and virtual background.

Table 1
Variation in the representation variables

Terrain	Buildings	Single trees	Forest
Pure terrain	Not present	Not present	Not present
Terrain with LANDSAT TM satellite image	Buildings as volumes	Single trees with texture	Forest with texture
Terrain with LANDSAT TM satellite image and orthophoto	Buildings as volumes and Buildings with texture (only in the foreground-scene)		

Fig. 3. View from the Groβer Mythen (real landscape).

Fig. 4. View from the Groβer Mythen (virtual landscape, shaded relief).

Fig. 5. View from the Groβer Mythen (virtual landscape, satellite image).

Fig. 6. View from the Groβer Mythen (virtual landscape, orthophoto).

The three different viewpoints were selected according to the following criteria. (1) The scenes have to be familiar to locals. (2) The three different scenes had to clearly fall in one of the three distance zones (see, e.g. USDA Forest Service, 1974) classified as background-scene (>5 km), middleground-scene (400 m–5 km/8 km) or foreground-scene (0–800 m).

The background-scene shows the view from the Großer Mythen on Brunnen and Schwyz. Because of its panorama views the Großer Mythen is a very popular mountain for hiking. The image contains no landscape elements in the foreground or middleground. The viewpoint selected as the middleground-scene is located on the Axenstrasse with a view towards Brunnen and Urmiberg. The Axenstrasse is a transit route to Italy. The image is dominated by elements within a middleground range. For the foreground-scene, a viewpoint was selected along the highway connecting Schwyz and Brunnen. The closest objects are within a distance of 100 m. Because of the topography of the valley bottom, the peaks of the Großer and Kleiner Mythen were visible.

The three different viewpoints were photographed with a 200 ASA slide film and a 55 mm lens, which relates to a field of view of ca. 45°. The slides were recorded on Photo CD.

The test set was evaluated by 75 test persons, grouped as non-local experts ($N = 27$), non-local lay persons ($N = 14$), local experts ($N = 13$), and local lay persons ($N = 21$). Experts were defined as people practising or being educated in a discipline related to spatial planning, such as architecture, landscape architecture, forestry, geography, etc. Locals were those persons living or working in the towns of Brunnen and Schwyz. The age of the test persons was within a range of 20–65 years, with an average of 40.2 years.

The test followed a standardized procedure. In the beginning, each test person had to fill out a short form containing questions about name, age, occupation, knowledge of the site and familiarity with three-dimensional representations. A short description and diagram explaining the test was handed out. Each test person also received an envelope containing the test images in random order. The test set consisted of images of 14 cm × 21 cm in size printed on a Canon CLC500 color laser printer. They were then asked to quickly flip through all 90 images before laying them down in front of the scale for evaluating the degree of realism. The scale consisted of five prints also in the size of 14 cm × 21 cm with numbers ranging from 1 to 5. The test persons were free to make changes any time they wanted to. There was no overall time limit. However, typically a test person took about 20–40 min to complete the test.

4. Results of the experiment

4.1. Evaluation by all

The degree of realism (R'Degree) and the associated average rank is calculated based on the mean scores for each image of all participants in the test. In addition, the evaluation is grouped as non-local experts, non-local lay persons, local experts, and local lay persons. Ratings according to the median and the modus as well as the standard deviation are given. The images on either side of the scale, i.e. the images with the lowest and the highest degree of realism have the lowest standard deviation, whereas those in the middle range have the highest standard deviation. This pattern has also been observed by Steinitz (1990) comparing standard deviation versus mean visual preference score.

It was expected that the three photographed scenes would score the highest R'Degree (Figs. 3, 7 and 9, Tables 5, 9 and 11). However, they did not receive an R'Degree of 5, but slightly lower. The next highest score is reached by the foreground-scene with a pasted foreground from the original photograph, and the background-scenes with the superimposed orthophoto (Fig. 12, Table 14). The scenes, which are shown as shaded relief have the least degree of realism (e.g. Fig. 4).

There are two major trends in the evaluation of the test set.

Table 2
Degree of realism: background-scene (average, ratings by all)

	Minimum	Maximum
Shaded relief	1.147	1.84
Satellite image	1.68	2.68
Orthophoto	4.067	4.307

Table 3
Degree of realism: middleground-scene (average, ratings by all)

	Minimum	Maximum
Shaded relief	1.08	1.747
Satellite image	1.347	2.493
Orthophoto	2.147	3.013

Table 4
Degree of realism: foreground-scene (average, ratings by all)

	Minimum	Maximum	Maximum (buildings without textures)
Shaded relief	1.053	1.973	1.533
Satellite image	1.693	2.827	2.12
Orthophoto	2.213	3.48	2.587

Table 5
Evaluation of the view from the Groβer Mythen (real landscape)

	Ranking	R'Degree	S.D.	Median	Modus
All	3	4.747	0.634	5	5
Non-local experts	1.5	4.926	0.378	5	5
Non-local lay persons	2	4.857	0.35	5	5
Local experts	3	4.769	0.421	5	5
Local lay persons	3.5	4.429	0.955	5	5

Table 6
Evaluation of the view from the Groβer Mythen (virtual landscape, shaded relief)

	Ranking	R'Degree	S.D.	Median	Modus
All	57	1.84	0.895	2	1
Non-local experts	58	1.778	0.916	2	1
Non-local lay persons	60	1.857	0.915	2	1
Local experts	57	1.692	0.606	2	2
Local lay persons	51.5	2	0.976	2	1

Table 7
Evaluation of the view from the Groβer Mythen (virtual landscape, satellite image)

	Ranking	R'Degree	S.D.	Median	Modus
All	25.5	2.68	0.851	3	3
Non-local experts	28	2.667	0.77	3	3
Non-local lay persons	26.5	2.857	0.99	3	3
Local experts	24.5	2.692	0.722	3	3
Local lay persons	29.5	2.571	0.904	2	2

Table 8
Evaluation of the view from the Groβer Mythen (virtual landscape, orthophoto)

	Ranking	R'Degree	S.D.	Median	Modus
All	5	4.307	0.765	4	5
Non-local experts	6	4.259	0.75	4	4
Non-local lay persons	8	4.357	0.61	4	4
Local experts	5.5	4.385	0.625	4	5
Local lay persons	5	4.286	0.933	5	5

1. In general, the degree of realism for the background-scene is higher than for the middleground-scene. The degree of realism in the middleground-scene is higher than in the foreground-scene (Tables 2–4). The highest rated computer-generated image showing the background-scene receives an R'Degree of 4.307 (see Fig. 6, Table 8), whereas the highest rating for the middleground-scene drops to 3.013 (Fig. 8, Table 10). The foreground-scene scores a value of 2.587 without texture-mapped buildings and 3.48 with texture-mapped buildings (Figs. 10 and 11, Tables 12 and 13). Buildings displayed with texture mapped facades score significantly higher than simple volumes.
2. The test images with the orthophoto are rated higher than the ones with satellite imagery. The test images with satellite imagery are rated higher than the ones shown as shaded relief (Tables 2–4, 6–8). However, depending on the elements present in the scene there is also an overlap between those three categories, i.e. in the case of scenes with satellite imagery or shaded relief the more elements (geometry) displayed the higher the rating is.

Overall, the background-scenes with the orthophoto nearly reach the scores for the photographs of the real landscape. Even without modelled 3D-objects these scenes reach a very high R'Degree. Because of the high detail in the orthophoto itself, unlike those scenes shown as shaded relief or with satellite imagery, an increased detail in geometry does not necessarily help to achieve a higher R'Degree.

On the other hand, in the middleground- and foreground-scene, the evaluation is strongly influenced in a positive way if 3D-objects, especially buildings, are modelled.

4.2. Evaluation by groups

Overall, the four groups non-local experts, non-local lay persons, local experts, and local lay persons exhibit an evaluation pattern which does not differ very much from one group to the other (see Fig. 13).

Looking at the evaluation between groups, it seems that the different groups use the range of the five point scale slightly different from each other. There is, for example, a tendency visible that non-local lay persons assign higher scores to the higher ranked images. Within this group, the best ranked simulations which are showing the background-scene with the draped orthophoto, are evaluated with an R'Degree between 4.286 and 4.571.

On the other hand, the group of local lay persons tended to rate the lower ranked images slightly higher. (It can be speculated that this has perhaps something to do with local knowledge.) The differences among groups explains why one simulation of the background-scene only consisting of the terrain with the draped orthophoto receives an R'Degree of 4.571 by the non-local lay persons, which is even higher than the score for the photographed landscape as evaluated by the local lay persons (4.429).

Within the group of the local lay persons, it is surprising that they assign a value of 4.429 for the foreground-scene consisting of a real foreground and a simulated background, which is the same as for the photograph from the Groβer Mythen — the background-scene.

Overall all four groups rate the simulated background-scenes with the draped orthophoto not only very high, but also higher than all other simulations. Only in one case, the local experts evaluate the foreground-scene with texture mapped building facades (R'Degree 3.692) higher than the background-scene with the draped orthophoto and the element single trees (R'Degree 3.615).

Compared with the other groups it is important to note that the local experts react more sensitively to the presence or absence of buildings in the simulation. For example, a simulated middleground-scene with a draped orthophoto but without buildings received a score of 2.077 by the local experts whereas the other subgroups rate the same image between 2.714 and 3.214. If the buildings are shown, then the same scene is rated similarly to the other groups (see, e.g. Fig. 8 which contains the single trees in addition).

The same applies to the evaluation of the foreground-scene. Furthermore, the simulations showing just building volumes without textured facades are rated lower than those scenes showing no buildings at all. This is surprising as the photograph showing the foreground-scene does contain buildings. Only the group of the local experts gives those images a significantly lower rating where buildings are not

Fig. 7. View towards Brunnen (real landscape).

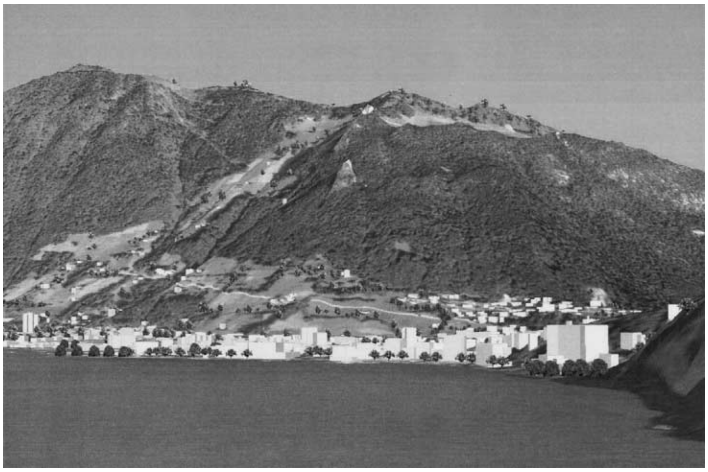

Fig. 8. View towards Brunnen (virtual landscape).

Table 9
Evaluation of the view towards Brunnen (real landscape)

	Ranking	R'Degree	S.D.	Median	Modus
All	1	4.96	0.255	5	5
Non-local experts	1.5	4.926	0.378	5	5
Non-local lay persons	1	5	0	5	5
Local experts	1.5	5	0	5	5
Local lay persons	1	4.925	0.213	5	5

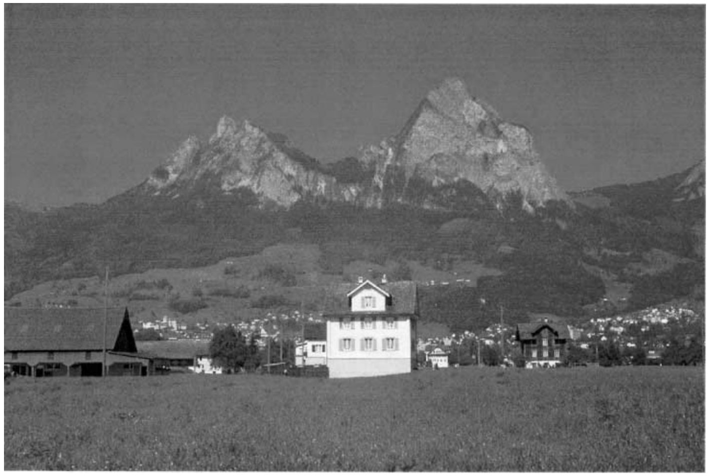

Fig. 9. View towards the Mythen (real landscape).

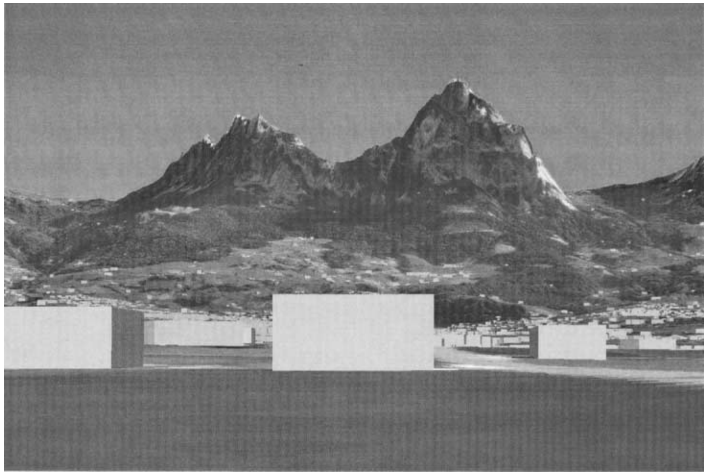

Fig. 10. View towards the Mythen (virtual landscape, buildings as volumes).

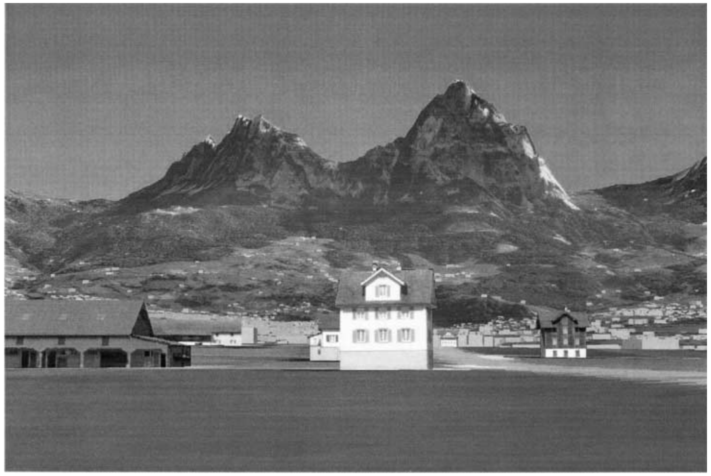

Fig. 11. View towards the Mythen (virtual landscape, buildings with textures).

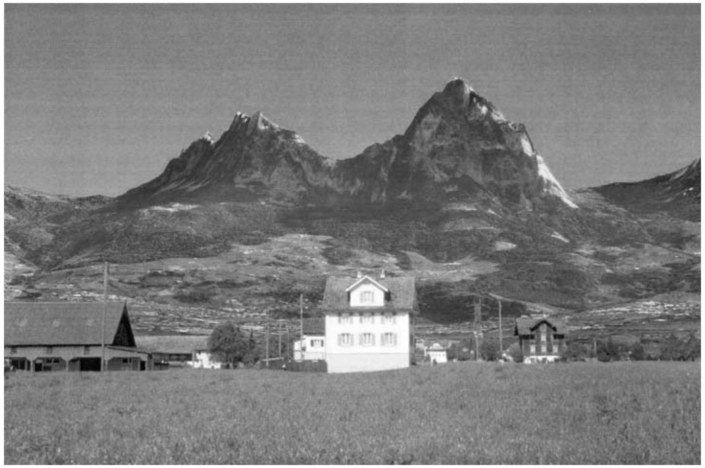

Fig. 12. View towards the Mythen (real foreground–virtual background).

Table 10
Evaluation of the view towards Brunnen (virtual landscape)

	Ranking	R'Degree	S.D.	Median	Modus
All	20	3.013	0.856	3	3
Non-local experts	21	2.926	0.766	3	3
Non-local lay persons	20.5	3.143	0.833	3	3
Local experts	17	3.154	0.769	3	4
Local lay persons	19	2.952	0.999	3	3

Table 11
Evaluation of the view towards the Mythen (real landscape)

	Ranking	R'Degree	S.D.	Median	Modus
All	2	4.827	0.551	5	5
Non-local experts	3	4.889	0.416	5	5
Non-local lay persons	3	4.714	0.589	5	5
Local experts	1.5	5	0	5	5
Local lay persons	2	4.714	0.765	5	5

Table 12
Evaluation of the view towards the Mythen (virtual landscape, buildings as volumes)

	Ranking	R'Degree	S.D.	Median	Modus
All	31	2.587	0.896	3	2
Non-local experts	24	2.741	0.699	3	3
Non-local lay persons	37.5	2.5	0.982	2	2
Local experts	28	2.615	0.923	2	2
Local lay persons	34.5	2.429	1.003	2	2

Table 13
Evaluation of the view towards the Mythen (virtual landscape, buildings with textures)

	Ranking	R'Degree	S.D.	Median	Modus
All	13	3.48	0.87	4	4
Non-local experts	16	3.296	1.012	3	4
Non-local lay persons	13	3.643	0.479	4	4
Local experts	12	3.692	0.821	4	4
Local lay persons	13	3.476	0.852	3	3

Table 14
Evaluation of the view towards the Mythen (real foreground–virtual background)

	Ranking	R'Degree	S.D.	Median	Modus
All	4	4.4	0.673	5	5
Non-local experts	4	4.37	0.675	4	5
Non-local lay persons	11	4.286	0.7	4	4
Local experts	4	4.538	0.499	5	5
Local lay persons	3.5	4.429	0.728	5	5

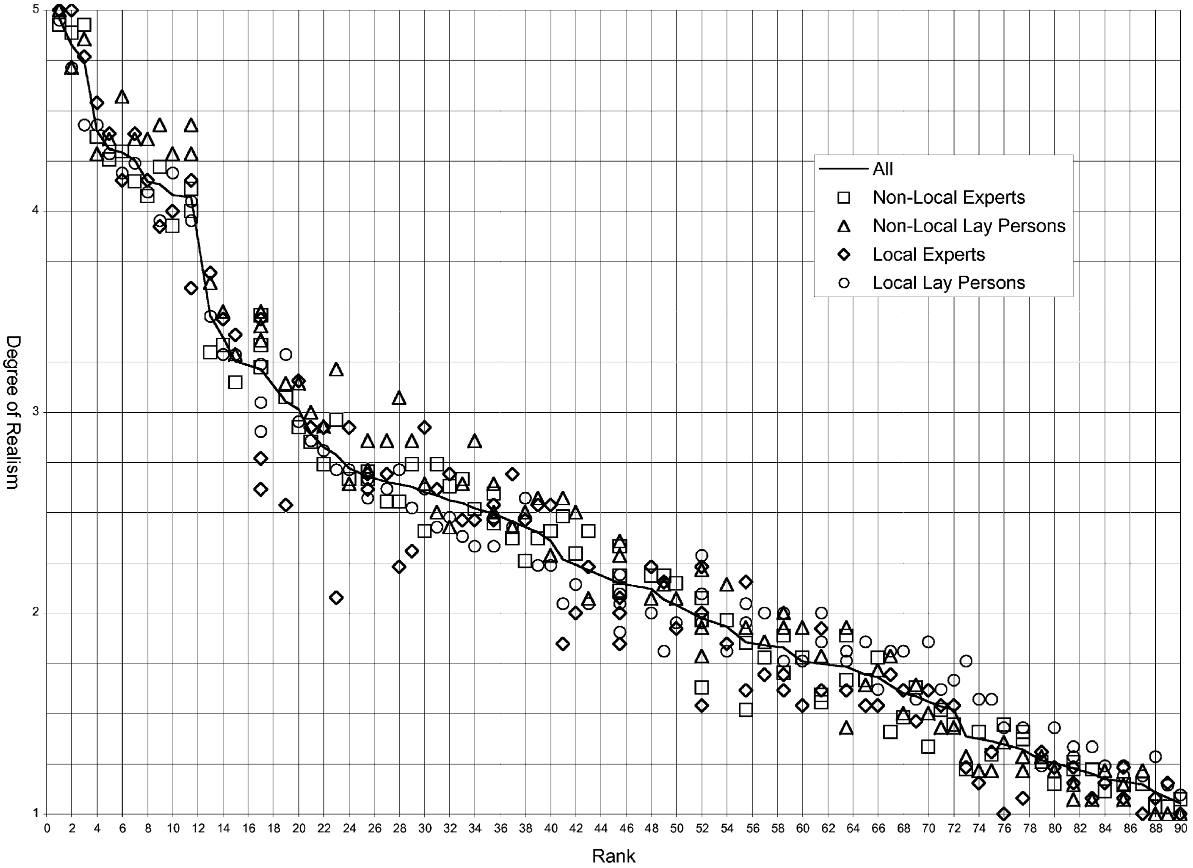

Fig. 13. Degree of realism and ranking: evaluation by experts/lay persons, locals/non-locals.

depicted in the simulation, i.e. recognizing the absence of the buildings which are present in the original photograph. Oral comments, which were received after the test, indicate that some test persons did not think of simple building volumes as sufficient representations of the reality. In comparison, if buildings with texture mapped facades are shown, consequently the R'Degree rises up more than one point on the five point scale. In the case of the local experts, the mean R'Degree for all foreground-scenes with orthophoto rises from 2.481 with simple volumes to 3.5 with textured buildings (see Table 15).

Table 15
Foreground-scene with orthophoto (images with buildings as volumes, textured buildings, or all images without buildings)

	Degree of realism (buildings as volumes)	Degree of realism (textured buildings)	Degree of realism (images without buildings)
Non-local experts	2.537	3.25	3.157
Non-local lay persons	2.339	3.464	3.214
Local experts	2.481	3.5	2.558
Local lay persons	2.262	3.238	3.024

4.3. Evaluation by individuals

Often in testing, such as in the Q-sort technique (Pitt and Zube, 1979) forced choice procedures are applied. The result of such a test can be in the form of a normal distribution, which allows the use of the data in parametric statistical analysis. In the test format as used in the presented case, the test persons have the free choice of how to sort the stimuli. Although in both approaches, the test result is of course subjective, the free choice sorting helps in finding the actual differences in the R'Degree from one image to the other in the rating, as it does not put an unnatural constraint on the decision-making. Therefore, the mean of the individual test result can differ from one person to the other, as it is up to the individual test person to use the range of the pre-defined scale differently.

The test persons followed two main approaches to the evaluation. 41 of 75 test persons classified the three photographs as R'Degree 5 and also put some simulations in this category — mostly showing the background-scene with the draped orthophoto. The next largest group of 16 test persons also classified the three photographs as R'Degree 5, but distributed the simulations across the categories 1–4.

Two other test persons put exactly three images showing the foreground-, middleground- and background-scene in category 5. However, of these they picked one of the simulated background-scenes with the draped orthophoto instead of the photograph. A group of nine test persons put between 4 and 17 test images in category 5, among them only two photographs. Three test persons put only two photographs in category 5. The third photograph and all the simulations were distributed in the categories 1–4. Three other test persons only gave one photograph an R'Degree of 5. Instead, they classified a number of simulations as R'Degree 5. One test person even had no photograph among the eight test images which were selected for the highest category.

The highest rated simulation of a virtual landscape (Fig. 6, Table 8) is put by 35 of 75 test persons in category 5. Overall, in the experiment, 56 of 75 test persons (approximately 75%) assign the highest possible value (R'Degree 5, 'very high degree of realism') at least to one or more scenes of simulated landscapes. In most cases, it is a background-scene, i.e. the middleground- and the foreground-scene are generally rated less realistic.

4.4. Analysis of variance

In order to determine the influence of the various elements of the virtual landscape on the degree of realism, i.e. the influence of the independent, categorical variables on the dependent, continuous variable, an analysis of variance (ANOVA) was performed. As all components of the virtual landscape are known, the contents of each scene can be controlled.

ANOVA is a robust test. The results are reliable, even when the original base data do not show a normal distribution.

Overall, the variance of the dependent variable (R'Degree) is nearly completely explained by the variance model. The values for the squared multiple R are within a range of 86.8% for the foreground-scene, 81.8% for the middleground-scene, and 97% for the background-scene. These high numbers can be explained by the controlled test environment.

In all three scenes, foreground-, middleground-, and background-scene, the variable terrain with its variations shaded relief, terrain with satellite image, and terrain with satellite image and orthophoto is by far the

Table 16
Analysis of variance: viewpoint Groβer Mythen (background-scene)[a]

Source	Sum-of-squares	d.f.	Mean-square	F-ratio	P
Terrain	130.197	2	65.098	1378.160	0.000
Buildings	5.775	1	5.775	122.260	0.000
Single trees	0.000	1	0.000	0.002	0.969
Forest	0.076	1	0.076	1.602	0.209
Lay/expert	0.322	1	0.322	6.807	0.011
Local/non-local	0.232	1	0.232	4.905	0.029
Error	4.346	92	0.047		

[a] Dependent variable: degree of realism; N: 100; multiple R: 0.985; squared multiple R: 0.970.

Table 17
Analysis of variance: viewpoint Wolfsprung (middleground-scene)[a]

Source	Sum-of-squares	d.f.	Mean-square	F-ratio	P
Terrain	26.386	2	13.193	173.487	0.000
Buildings	3.713	1	3.713	48.831	0.000
Single trees	0.459	1	0.459	6.029	0.016
Forest	0.466	1	0.466	6.134	0.015
Lay/expert	0.311	1	0.311	4.095	0.046
Local/non-local	0.120	1	0.120	1.578	0.212
Error	6.996	92	0.076		

[a] Dependent variable: degree of realism; N: 100; multiple R: 0.905; squared multiple R: 0.818.

Table 18
Analysis of variance: viewpoint Widen (foreground-scene)[a]

Source	Sum-of-squares	d.f.	Mean-square	F-ratio	P
Terrain	51.769	2	25.885	354.155	0.000
Buildings	12.322	2	6.161	84.295	0.000
Single trees	0.409	1	0.409	5.595	0.019
Forest	0.108	1	0.108	1.480	0.226
Lay/expert	0.036	1	0.036	0.499	0.481
Local/non-local	0.006	1	0.006	0.078	0.781
Error	9.867	135	0.073		

[a] Dependent variable: degree of realism; N: 144; multiple R: 0.931; squared multiple R: 0.868.

most important of all variables (see the sum-of-squares in Tables 16–18). By far less, but still second most important in all three scenes, is the variable buildings. Compared with the variables terrain and buildings, all other variables, i.e. single trees, forest, lay person/expert, and local/non-local are not important.

The result of the ANOVA confirms the results gained through the descriptive statistic techniques. It is not surprising that single trees and forests do not contribute more to the R'Degree as in none of the scenes the vegetation is as dominant as an element of the landscape as the two variables terrain and buildings.

5. Summary and conclusions

5.1. Possible consequences for the planning disciplines

We are living in an era of visual communication. If the planning disciplines want to be better understood by the public, they have to work with and in the three-dimension — the real world is three-dimensional as well.

Nevertheless, the planning disciplines are still mostly failing to use virtual landscapes as an important part in communication with others. On the other hand, even the best simulation is only a representation of the real world. A virtual walk-through is not the same and will never be the same as a real walk in nature. However, for planning, not only the existing but even more the future condition of the landscape is of special interest. This is why the use of virtual landscapes in planning will become increasingly important.

So far, the planning disciplines have only just begun to utilize 3D-visualization techniques. Because of the flexibility offered by 3D-visualization techniques in terms of space and time — retrospective as well as prospective — their potential use is manifold. Over a short period of time the change of the landscape often seems to be slow, thus being hard to recognize. By means of computerized visual simulation, the past and the present or even the future, as expressed by scenarios or plans, can be seen side by side. Using visualization techniques the 'world' can be represented like in time-lapse photography and the changes can be made visible.

Currently, visualization is mainly understood as a presentation medium for the result of the planning process. Shifting from the traditional 2D-planning towards 3D-planning while integrating visualization as a representation of past, present and new landscape situations could offer improved support for better and more informed decisions about the spatial organization of the landscape. Because of the hardware, software, and especially the data requirements, and the time typically needed to produce detailed, large-scale landscape visualizations they are generally being considered a luxurious addition to the overall planning process.

An essential requirement for visualization to provide a substantial contribution in planning is the comprehension of visualization as an integrated and at the same time integrating part in the planning process, facilitating improved communication among experts and lay persons, i.e. among planners and the persons affected by planning.

5.2. Degree of realism

Typically, in those cases where virtual landscape representations are used in planning, once there is a final product, instead of questioning the validity of the visualization, the general attitude is expressed as "doesn't it look great?". Systematic research in this field so far is fragmentary.

The presented research has proved that three-dimensional representations of the real world can provide experts and non-experts as well as locals and non-locals with imagery closely coupled with direct human experience. The highest-rated virtual landscapes reach a degree of realism which makes them very hard to be identified as computer-generated imagery. They are valid representations of the real landscape. In the experiment, approximately 75% of the test persons assign the highest possible value (very high degree of realism) to one or more scenes of simulated landscapes. In most cases, it is a background-scene, which is placed in this category. The middleground- and the foreground-scene are generally rated less realistic than the background-scene because of their relatively lower level of detail, but they still reach a medium to high R'Degree. The evaluation of the digital photomontage consisting of a virtual background and a real, fully detailed foreground indicates that more detailed modelling would be necessary to reach into the very high R'Degree range. This image achieves an R'Degree of 4.4, whereas the highest rated completely virtual scene scores an R'Degree of 3.48. The data and time needed to push up the R'Degree approximately one level up to 4.4 would be enormous.

On the other hand, it can be argued that even simulations with a lower degree of realism can still contain the most important information needed for a specific purpose. For example, representations used in flight simulation should have an overall realistic impression. However, there is no need to contain detailed landscape features. Most important for these kinds of applications are factors like functionality and interactivity and the ability to display, e.g. potential obstacles, which could be of importance during the landing procedure.

Overall, a virtual landscape with a very detailed orthophoto and 3D-objects can represent a certain landscape highly realistically. Still Bergen et al. (1995, p. 136) comment on the use of remote sensing data as follows: "The usefulness of a draped image system for landscape assessment has not been shown". The results of this experiment show that even with the fairly crude resolution of the satellite image a relatively realistic visual representation of the overall impression of a landscape (i.e. background-scene) can be given. 'True color' satellite imagery at a resolution of 25 m does not provide enough detail to clearly show the actual land use. In order to fill this information gap and to achieve a higher R'Degree digital orthophotography which is becoming widely available, is necessary.

One has to keep in mind that the image information only reflects one moment of one day of the whole year. The real landscape is a dynamic system undergoing continuous seasonal and daily change of atmospheric conditions. This diversity and variation cannot be captured in a simulated environment. Potential limitations become obvious when the real landscape is set against the virtual landscape.

5.3. Data outlook

Essential for landscape visualization are data, preferably 3D data. Currently, we are in a phase where a lot of 2D data (especially related to building information) is or will be collected disregarding the fact that in the near future 3D data instead of 2D data will be increasingly needed in environmental planning. Therefore, one of the major obstacles for the spreading of advanced applications in planner's practices, like GIS-based visual simulation techniques, is related to the availability of data ready to use. Many data sets are either not sufficient in resolution or do not cover the needed information for landscape visualization. The only true 3D data widely available are digital terrain models. Their resolution is still relatively coarse, i.e. in the presented example it has a resolution of 25 m. Also, high-resolution orthophotos have been increasingly used in recent years.

Automatic procedures to generate 3D-objects from 2D data, i.e. having the 3D modelling based on numeric data from the 2D database, can bridge the gap between the (mainly) 2D GIS systems and 3D-visualization systems. It can be foreseen that in the near future measured 3D data instead of 2D data will be increasingly available for planning purposes such as for the visualization of potential future landscape change. Research in photogrammetry is directed towards semi-automatic interpretation of aerial photographs in order to provide 3D-building data including the actual roofs. Providing the associated specific building textures will be a problem because the generation of these textures is highly labor-intensive. On the other hand, the value of using generic textures instead for buildings is at least questionable, especially if the visualizations are shown to locals who are familiar with their buildings, and especially when compared with the actual photograph.

Acknowledgements

Digital orthophoto© Swissphoto Photogrammetry and Surveying DHM25© Swiss Federal Office of Topography (BA 013197) LANDSAT TM scene courtesy of Image Science Division, ETH Zürich.

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