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Three-Dimensional Synthetic Landscapes: Data Acquisition, Modelling and Visualisation

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ABSTRACT

The extension of geographic information systems (GIS) into the 3rd dimension is increasingly gaining importance. Today, the realisation of truly 3-dimensional GIS solutions is not yet in view due to their enormous complexity. However, it is possible to represent 3-dimensional spatial information using flexible data structures, which automaticaly adabt to the object specific requirements and charakteristics, such as object type, location and amount and complexity of the available information. This approach allows to utilise efficient data aquisition methods such as the automatic interpretation of existing maps based on pattern recognation techniques. Even a minimum of 3-dimensional information extracted from such 2-dimensional information sources allows for effective landscape visualisations, very interesting environmental analyses and simulations in a wide range of applications.

1. INTRODUCTION

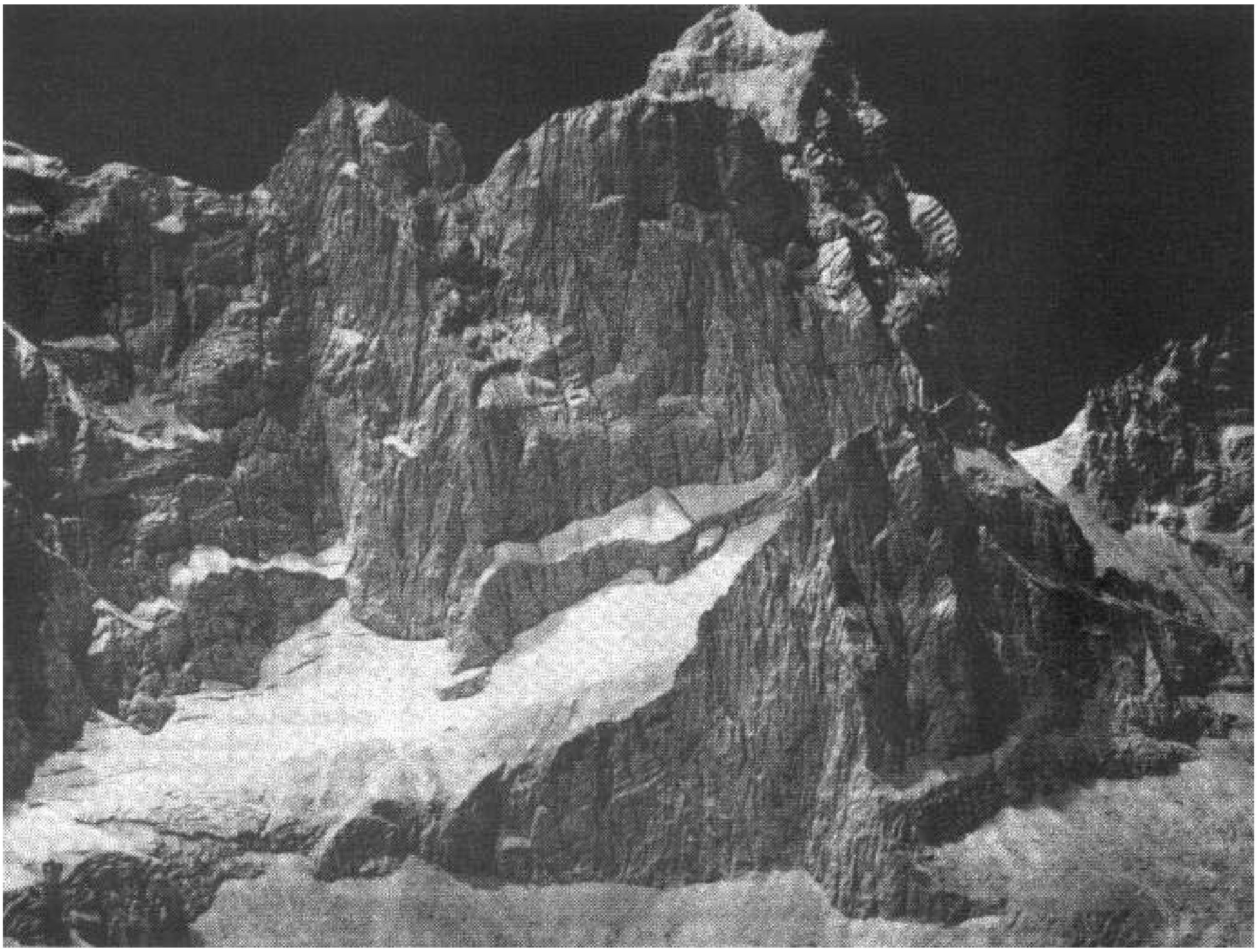

Figure 1: Model of the "Grosse Windgällen" created by Eduard Imhof at the Institute of Cartography for the national exhibition of 1939.

Traditional topographic cartography is often portrayed as being the art of representing terrain in the form of a strictly two-dimensional graphic model, a limitation which was imposed by the state of technical development. In fact, reproduction methods (offset printing, copper engraving, lithography, photographic processes, etc) called for the use of a single flat map projection for the production of

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large map series intended for the most varied uses. Planimetric plotting has been, and still is today, the most flexible solution which can be brought to bear on this problem. If information on the third dimension is required, it is transformed into planimetric elements such as contours or textual annotations such as spot levels or other numerical representations. These can be printed or drawn without difficulty but they result in losses of information and present an obstacle to immediate visual interpretation.
That explains why, from time to time, cartographers have tried to escape from the classical planimetric straitjacket into the dream of a three-dimensional cartographic model.
Production costs as well as the space needed both for the use of such relief models and for their archiving were however too great for significant progress to be made.
The evolution from graphical representations to digital models such as are found in today´s spatial information systems permits the realisation of such dreams, although the reality thus attained can at best only be virtual.

2. THREE-DIMENSIONAL GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

2.1 Principles of modelling

The methods used for the modelling of geographical features are currently based on relational data structures in the majority of two-dimensional applications. The extension to the third dimension of the models employed is entirely feasible.

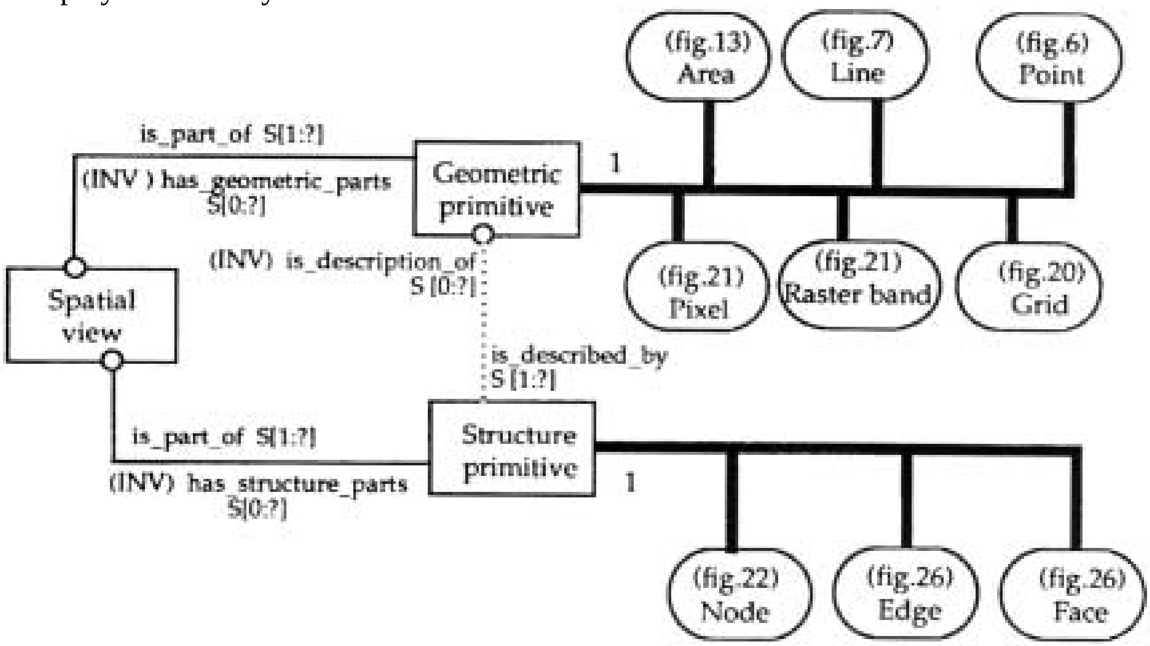

Figure 2: The most important components of the geometric model (CEN Doc N320, Geographic Information - Data Description - Geometry, draft of 28.2.95).

The geometric part of the model must be extended from areas to volumes. The modelling possibilities can be formulated through a generalisation of the representation of topography, by proceeding from the concept of "nodes and edges" to that of "faces". (European Standards Project CEN TC287, document N329). This can be extended to volumes without too much difficulty.
The thematic part of the model, sometimes also called the semantic model, is not affected by the number of dimensions. The underlying components, whether for simple or complex objects, continue to be definable in the form of classes of entities with their lists of attributes as well for three-dimensional as for two-dimensional objects.

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The alternative use of other systems such as object-oriented modelling should not present any particular difficulties.

2.2 The development of three-dimensional GIS

Once above the conceptual level the difficulties escalate. Our perception of space is very frequently reduced to planimetry alone. In fact, to take just two examples, the definition of the extent of an administrative area such as a commune or of a property for land taxation purposes, in terms of three-dimensional objects, is not a straightforward matter. That is primarily because neither under the law nor for everyday affairs has the trouble been taken to determine with any precision the vertical extent of such objects. Under Swiss Law, for example, landed property extends to the subsoil and its mineral resources as well as to its airspace "in all the height and depth relevant to its enjoyment" (Swiss Civil Code, Article 667).
But even for better defined objects such as a lake or a geological deposit, the definition is not simple.
Data capture constitutes a second obstacle. The quantity of information required is huge and the investment of time and money needed to obtain structured three-dimensional data soon exceeds reasonable limits.
The idea of a fully three-dimensional GIS can thus only be applied to very simple cases for spaces of small extent such as a part of a town or a single industrial site, for which models can reasonably be established reasonably.

2.3 "2.5-dimensional" models

The difficulties described above and the fact that software available in the marketplace allows only for two dimensions, with a rigid planimetric model of geometry which can not be extended by the user, have led to the development of pragmatic solutions. These allow for some geographical features to be managed in a two-dimensional way in an ordinary GIS, while a small part of the model (in principle the surface which describes the terrain itself) is handled three-dimensionally by means of specialised digital terrain model (DTM) software.
The most modern GIS, useable for example in conjunction with photogrammetry, employ more than one three-dimensional geometric model in their metric (coordinate geometry) component. Such multiple models can then be used for the management of point and line data in three-dimensional space. Examples may include the underground electricity network, drinking water mains, obstructions to aerial navigation (masts, cables, etc), tunnel alignments, and so forth.

2.4 Models with variable structure

An interesting solution is offered by adaptable structures, for which the number of dimensions and the complexity of their elements are modified in accordance with the requirements of a given case. Their basis is a simple structure which can be managed by an ordinary GIS or can even rest on a raster backdrop. To these basic data can be added a DTM, following the "2.5-dimension" concept described above.
At the third level, limited to objects of special interest, information which is effectively three-dimensional is held, which can be adapted to the complexity and importance of the object.
The structures to be used must be defined at the stage of setting up the model. At the first level of the structure, three-dimensional data can be considered as an attribute which does not fit the first normal form of databases, as it does not contain elementary information but on the contrary information which is structured in its turn (NF^2 database).
To illustrate this idea with an example, let us structure the three-dimensional information about a building to several levels of complexity which may then be selected in accordance with a given need:

- the height of the building and of the roof (2 numerical values),
- the construction of prisms or other elementary volumes,
- a complex volumetric construction produced with an architectural CAD system,
- etc.

Other geographical objects can be structured differently depending on the requirement. The level of complexity is also variable and should be parameterised.
The model that we use in our research area allows us to move by stages from conventional two-dimensional modelling to more complex models, in part using software available in the marketplace.

3. DATA CAPTURE

3.1 The planimetric background

The information required for a GIS based on a variable model structure is mainly planimetric at the outset. The classical techniques for data capture are well known: field surveys, photogrammetry, GPS positioning, and so on.
As each new information collection process is costly, it is always well to make use of existing digital geographic data. The issue of transfer between different data structures is currently being energetically addressed in Europe (CEN TC287, European standards in course of development, Gnägi, 1995).
If the necessary data already exists, but only in graphic form, the digital conversion of plans and topographic maps may provide an economic solution. Accuracy (depending on the graphic medium, the scale, etc) and currency (state of revision) constitute the limitations of this method.

3.2 Automated digitising of plans

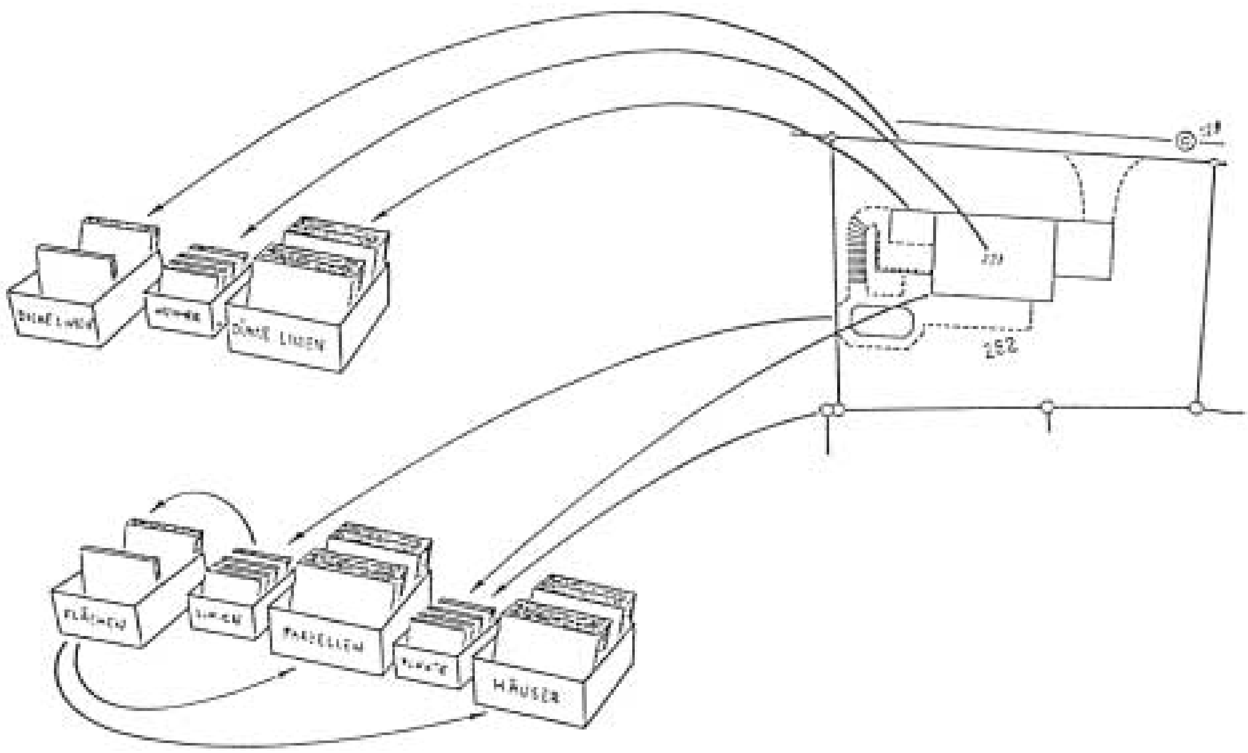

Figure 3: The difficulty of the automatic digitalisation depends on the structure of the data.

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Considerable progress has been achieved in recent years and present day techniques can often be used successfully even if the source graphics (such as topographic maps) contain a great deal of diverse detail. The level of difficulty to be overcome in the automatic digitising of a map depends mainly on the data structure of the information system for which it is destined. Automatic digitising means the identification of geographical features, and the determination of their position and their classification in the intended data structure.
If the desired model is structured in a regular grid (raster data) and the thematic content is restricted to the reproduction of a cartographic image, data capture can be totally automated by the use of a scanner.
Progress in recent years does also offer effective solutions which allow the automation of a substantial part of the work even if the data structures are more complex. The following paragraphs are limited to the description of a few significant recent developments.

3.3 Automated reading of topographic maps

Some years ago, efforts were concentrated on large scale applications such as cadastre and utilities' network plans.
As the graphic bases were simple, the following procedure was adopted in most cases : scanning, then raster to vector conversion followed by classification of objects in the vector database. Research carried out by the University of Hanover (Illert, 1992, Meng 19xx) illustrates this approach, which forms the basis of powerful commercially available software.
Topographic maps at scales from 1:10 000 to 1:100 000 allow large areas to be covered more quickly and are thus of interest for land management (regional planning), environmental GIS, etc. The main characteristics of topographic maps are the rich variety of thematic information portrayed and their geometric accuracy (with minimal generalisation), as well as the use of complex and numerous graphic devices (several hundred different depictions covered by symbols, conventional signs and lettering).
The interpretation required is far more complex for topographic than for cadastral maps, which becomes all too apparent when one tries to use automated classification techniques directly on the data in raster form. Even if the goal, the complete understanding of the content of a topographic map, is for the time being unattainable, the methods developed recently show that a certain level of success can be achieved. We do now have automated procedures which allow the recognition of particular elements of a map, in the form of a succession of operations which are completed by means of manual corrections where these prove necessary.

3.4 Comparison of images by correlation

The well-proven procedure of "Template Matching" is one of the methods most commonly used for object recognition in raster images. It is based on the following principle: a predefined model, in raster image form, is compared with a portion of the target image of the same size, then displaced within the latter column by column and row by row. From this series of comparisons can be deduced the degree of correspondance between the model and the portion of target image concerned. When this exceeds a predetermined threshold value, the model is deemed to have been recognised. The template matching procedure thus rests on the comparison of two images, which, in the case of digital image processing, is translated into correlation calculations. The correlation coefficients, on which the calculation of the degree of correspondance is based, are defined by grey values of the corresponding pixels in the two images. More varied correlation models can be envisaged in theory, but in practice we restrict ourselves to models which are easily manipulated, both mathematically and in terms of the computation techniques which they demand.

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Standard methods to measure similarity at (X, Y) of Template and Image:

Template $T(z,s)\ ,\ 1 \le z \le m,\ 1 \le s \le n$

$$\Big\}\ m \le M, n \le N$$

Image $B(x,y)\ ,\ 1 \le x \le M,\ 1 \le y \le N$

$$d^2(X,Y) = \sum_{z=1}^{m}\sum_{s=1}^{n} \{B(X+z,Y+s) - T(z,s)\}^2 \quad \text{("Euclidean Distance")}$$

$$= \sum_{z=1}^{m}\sum_{s=1}^{n} \{\underbrace{B^2(X+z,Y+s)}_{\downarrow\text{const.}} - 2\cdot B(X+z,Y+s)\cdot T(z,s) + \underbrace{T^2(z,s)}_{\downarrow\text{const.}}\}$$

d = 0 for an exact match, otherwise d>0
d -> min. searching a minimum value

a simpler measure of match
instead of the square sum

"Cross – Correlation"

$$\sum_{z=1}^{m}\sum_{s=1}^{n}\{B(X+z,Y+s)\cdot T(z,s)\} \rightarrow \text{Max.}$$

"Laplace – Distance"

$$L(X,Y) = \sum_{z=1}^{m}\sum_{s=1}^{n}|B(X+z,Y+s) - T(z,s)|$$

Figure 4: Similarity measure by "Cross-Correlation" or "Laplace-Distance".

The advantages of this method are clear : both the concept and the algorithms involved are simple and controllable.

The method of template matching needs further improvement in two main respects, if its full potential for the recognition of cartographic objects is to be realised. Its robustness in the face of variations in the size and orientation of the elements to be recognised, and the performance of the correlation computation itself, are both in need of attention. The figure illustrates an optimisation principle which is particularly effective and which draws on the idea that the pixels in a model are not all equally important in the recognition of a cartographic feature. For the text character shown, the pixels do not all have the same degree of significance. The insignificant elements of the image, essentially any lines or points which do not form an integral part of the object, must not be allowed to interfere in the image comparison and are masked for this reason. The degree of importance of the different pixels in the correlation computation is taken into account numerically by the biasing effect of differential segmentation and weighting which form part of the particular definition of each model and form the basis of the high level of efficiency of this process.

Provided that the models to be compared are carefully defined (i.e. that emphasis is clearly placed on the important parts of the image and that those parts which are not important are masked) , it is possible to achieve very much higher levels of success in object recognition with this method than with traditional correlation techniques.

Image comparison takes place in stages, a test of the degree of matching being done at the end of each stage. The correlation computation is only done when a good enough match has been achieved.

The software was developed using the expert system model. Its special feature is its knowledge base, which is graphic rather than being a formal collection of facts and deductive rules (Stengele, 1995).

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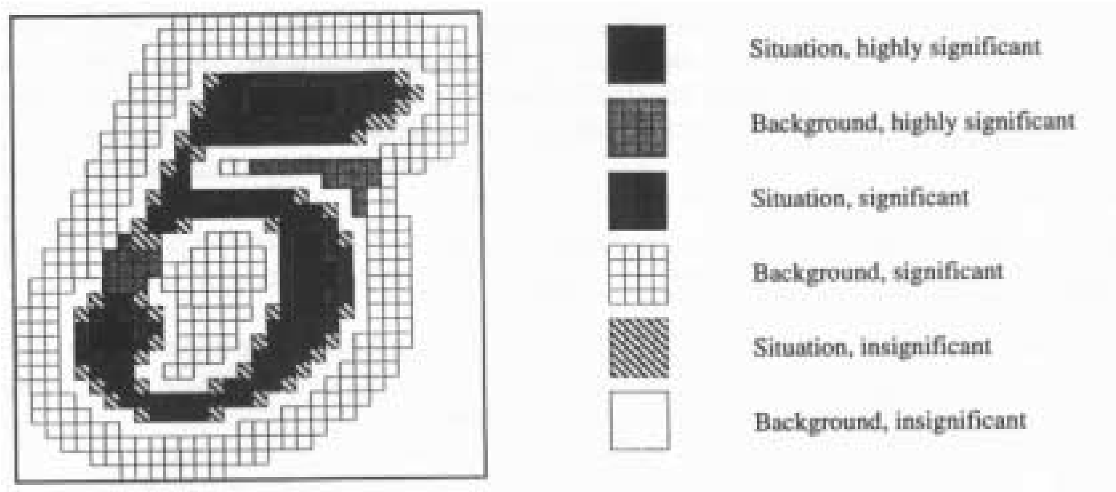

Figure 5: Template definition with significance levels.

3.5 Extraction of two-dimensional (areal) objects

The identification of areal objects, such as the buildings on a topographic map (Nebiker & Carosio, 1995), is achieved by separating them from other cartographic features in the image. This is a more complex task than the recognition of individual letters or symbols and requires the combination of a series of different processing steps. In principle, the first step is to eliminate unnecessary information (text, symbols, grid lines etc). This may be done by using the knowledge-based template matching process described above. The additional computational effort and time required for this preliminary step are justified by better recognition results and the reduced effort in the subsequent verification and editing stages.
The actual recognition of areal objects is achieved by applying a series of raster processing operations especially adapted to the characteristics of cartographic data. The main operations applied are dilatation, erosion and noise suppression filtering (Göpfert, 1991). Additional possibilities to enhance the extraction of areal objects are again offered by template matching operations using square or cross-shaped templates.
The "KAMU" software package developed at the Surveying Science Department of ETH Zürich uses its own macro language to control the sequence of raster processing operations. This allows customised script files to be written in order to cater for different cartographic conventions or graphical standards.
The recognition of areal objects is typically followed by a vectorisation and structuring process, for which the quality of recognition results is a key factor.

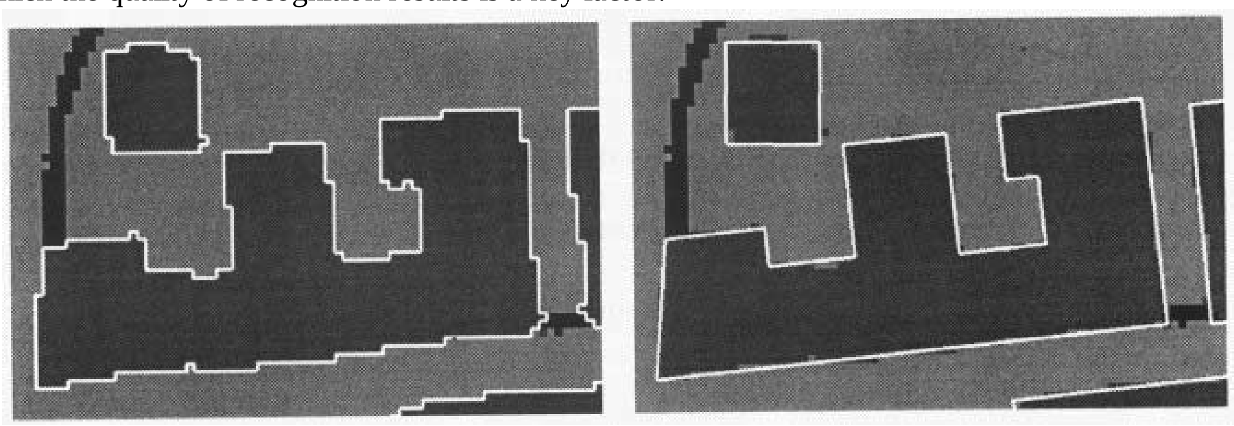

Figure 6: Raw contour polygons and automatically adjusted object contour segments (using geometric constraints and robust estimators).

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This very flexible solution yields a success rate in identification which exceeds 95%. To achieve 100% success a manual verification and editing process is still required (Stengele, 1995). The objects thus recognised in the raster image must be transformed into features in the GIS. Object-by-object vectorisation taking account of the particular characteristics of each class of object leads to the desired data structure. Robust estimators can be used for the extraction of nodes and edges so as to facilitate the determination of their characteristics (Nebiker, 1994).

3.6 Extraction of height information

The creation of partially three-dimensional GIS is heavily dependent on the economical acquisition of data. Maps and plans contain altimetric information which may only be implied or may be explicitly coded. Automatic interpretation could be extremely worthwhile.
The following applications give an idea of the possibilities offered by this technique:

- The totally automatic reading of spot heights in metres from the topographic map allows a DTM to be computed without any manual intervention. A test on the Lucerne sheet of the Swiss national map series at 1:25 000 (covering 17.5 km x 12 km) yielded a DTM with root mean square height accuracy of the order of 20 m within a few hours(Stengele, 1995).
- The partially (80%) automated identification of contours on the national map at 1:25 000 forms the basis of the Swiss national DTM (MNT 25) (Eidenbenz).
- The totally automatic digitising of conventional signs or topographic features allows synthetic perspective views to be produced even if height information is lacking (Zanini).
- In a research project in collaboration with Telecom-PTT (Posts and Telephones) (J F Wagen), it proved possible to compute signal strengths for mobile phones in an urban area thanks to the automatic recognition of buildings from the topographic map (Nebiker, 1994).

4. SYNTHETIC PANORAMIC IMAGES

4.1 Applications

The totally or partially three-dimensional information handled in a GIS leads to the idea of reconstructing synthetic panoramic views as an aid to the interpretation of complex themes. From one viewpoint, one set of planimetric data, one DTM and other implicit or explicit altimetric information, it is possible to create perspective models of the landscape for a multitude of applications.
Here are several examples :

- Regional planning (visibility studies, environmental impact and modification of landscapes, consequences of urban development, etc),
- Integration of major civil engineering works into the landscape (hydro-electric dams, bridges and viaducts, transport links),
- Visualisation of air navigation obstacles (masts, cable car lines, electricity cables, towers and spires),
- Simulations and animations (instruction and training, visualisation of dynamic processes, etc).

4.2 The creation of an experimental three-dimensional visualisation GIS

The demand for three-dimensional visualisations has greatly increased in recent years.
A panoramic view is much easier to interpret than a list of coordinates or a planimetric representation. For example, cartographic perspective views in which the major features of the terrain are represented by three-dimensional symbols can be especially useful.

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Even if the data currently available are very limited, some requirements can already be satisfied. If the height data consists only of a DTM, it is still possible to enhance it by using information implicitly contained in the planimetric data, which can be identified and interpreted automatically.
In a very recent project (Zanini, 1995) we have combined several sources of data to demonstrate the effectiveness of this technique. In particular :

- a raster topographic map at 1:25 000 for planimetry with
- an altimetric background consisting of a DTM (MNT 25) at the same scale.

Figure 7: 3D-Visualisation of the map 1:25 000 with automatically recognized trees and towers.

In the first stage of the work the initial data were enhanced by objects identified automatically on the planimetric image as follows:

- buildings (constant height of 10 m),
- trees (constant height depending on the symbol used),
- towers and spires (constant height).

The combination of these few modest sources of information already allows very worthwhile results to be achieved. A small quantity of height data such as the height of an aerial mast or the number of storeys in a building could lead to a further gain in quality of three-dimensional information.
The visualisation of the synthetic view is effected with the help of modern graphic languages such as PHIG or OPEN GL, which allow the nature of the surface, the illumination, the orientation of surfaces, and specular and diffuse reflections all to be taken into account (Zanini, 1995).

5. CONCLUSION

The development of totally three-dimensional GIS will keep us busy for several more decades. The complexity of data structures and the acquisition of the information are the difficult obstacles to be surmounted. We do however have several possibilities for the creation of partial solutions which may be quite effective and worthwhile. These rest on the use of variable data structures and the automatic identification of implicit three-dimensional information, and on a representation of landscapes and their significant thematic features by synthetic images.

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