3D Cadastre: Progress Report

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Summary:

At the Department of Geodesy, Section GIS technology a research is carried out to study the needs, possibilities and constraints for a 3D cadastre. This study is carried out in collaboration with the Netherlands' Kadaster. The aim of the research is to build a prototype of a cadastral registration system which takes into account the vertical aspects of rights. This PhD research started in the summer of 2000 and will last till June 2004. This report summarises the results so far and it describes the planned activities.

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Contents

1 Introduction

In the summer of 2000 I started my PhD research with the subject '3D cadastre' in which the needs, possibilities and constraints of a 3D cadastre are studied. The study is carried out in collaboration with the Netherlands' Kadaster. Juridical input for the research is given by H. Ploeger, Section Geo-information and Land Development. The aim of the research is to build a prototype of a cadastral registration system that is capable to provide insight into the vertical dimension of rights on real estate that are registered in the Public Registers. This report summarises the results of the last two years and describes the planned activities till the end of this study (June 2004).

2 Results of June 2000 - October 2002

2.1 Background of the research

The research was started with an investigation to the current registration practice of 3D situations to look for the actual needs for a 3D cadastre [1] [2]. In this investigation registrations according to Private Law as well as registrations according to Public Law have been taken into account. A paper was written to explore the background of the 3D cadastre topic [15] to come to a concept of a 3D cadastre: what actually do we mean by a 3D cadastre and what needs need to be fulfilled.

2.2 Concept of a 3D cadastre

Before we came to a concept of a 3D cadastre three solutions where studied [5] [6] [7]:

- a full 3D cadastre (partitioning of space into 3D parcels)
- a hybrid solution (keeping current 2D cadastre with an extension for 3D situations)
- 2D cadastre with a tag to 3D situations (as is current practice)

Based on this study we came to the most feasible solution for the near- to mid-term future: the hybrid solution. This concept of a 3D cadastre has been based on both technical and cadastral considerations. In the hybrid solution rights and limited rights are still registered on 2D parcels, but 3D situations (complex situations) are registered in addition. Complex situations refer to cases of multiple use of space: one parcel is used by several people - full owners and/or holders of limited real rights - each holding a right on the parcel, each right limited in the third (and second) dimension. There are several alternatives for the registration of 3D situations in the hybrid solution. In this research two alternatives have been studied as will be described in the next section.

2.3 3D right-objects and 3D physical objects

2.3.1 3D right-objects

For the registration of 2D parcels and 3D situations in one system, a relative simple solution is the starting point. We start with the current cadastral registration system

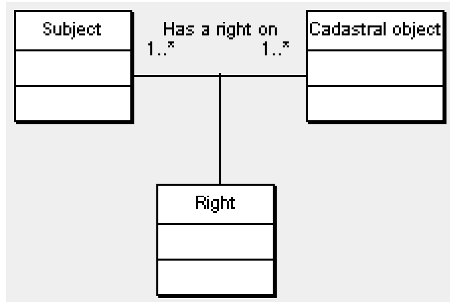

Figure 1: UML model of the current cadastre

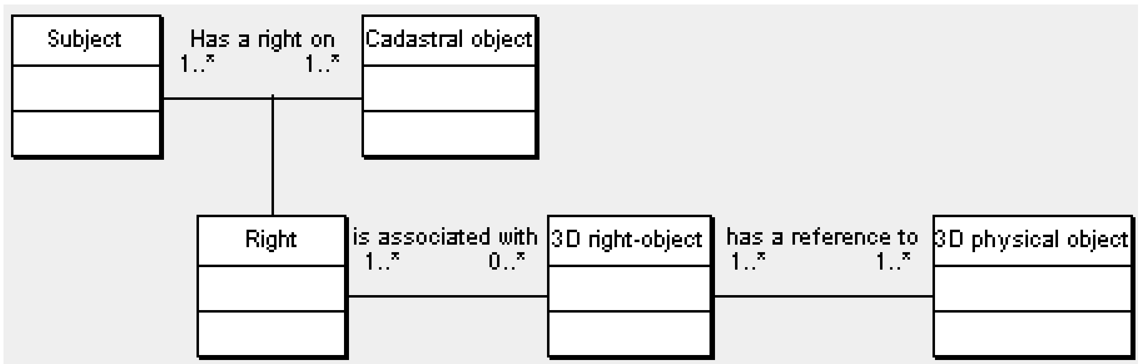

Figure 2: UML model of the current cadastre extended with the registration of 3D right-objects

(figure 1) and extend this with the possibility to register rights concerning 3D situations in 3D (3D right-objects) (figure 2). A 3D right-object is a 3D representation of a right that is established on a 2D parcel and concerns a 3D situation, for example a right of superficies established for a tunnel that is limited in the third dimension. The boundary of this 3D representation starts with a 2D polygon (footprint) which is usually the parcel boundary. This boundary is extended into 3D by means of defining the upper and lower limits of the right [8]. In this way a parcel can contain a stack of volumes. When more detail is needed in x,y dimension (for example in the case of a tunnel which intersects only with part of a parcel) the parcel needs to be subdivided to obtain the footprints where the right applies for. The 3D right-object is seen as an approach to get insight in the 3D aspect of rights ('visualisation of rights in 3D'): it is not an exact representation on which conclusions with juridical consequences can be drawn. The (factual) ownership information can be found by tracing the subject(s) that has (have) the right that is associated with the 3D right object. 3D right-objects refer to a 3D physical object. Information on the 3D physical objects can be maintained inside or outside the DBMS. The DBMS should at least contain id's of the 3D physical objects. In this way all 3D right-objects belonging to one 3D physical object can be found.

2.3.2 3D physical objects

A more advanced solution is the registration of 3D physical objects in addition to 2D parcels (figure 3). In this case the existence of a 3D physical object (tunnel, complex building) forms the base for registration. A registration of 3D physical objects needs to be organised and maintained and this registration will become a cadastral task. For the implementation of this registration a finite list of objects that need to be registered has to be made. When 3D physical objects that are defined on the finite list occur, they have to be registered. To make the registration indisputable, a law is needed to make the registration obligatory. In the registration system spatial as well as non-spatial information on the whole 3D physical object is maintained. A 3D physical object can be queried as a whole. For example: which parcels are intersecting with the (projection) of a tunnel; which rights are established on these parcels; who are the subjects who own these rights. The holder of a 3D physical object is a subject (or more than 1 subjects) with a right on the 3D physical object by means of (limited) rights on the intersecting parcels (factual ownership which is not the same as the juridical ownership). In general the holder of a 3D physical object is the person or organisation who is responsible for the 3D physical objects and uses the object as if he were the owner. The hold relationship between a subject and a 3D physical object is stored explicitly apart from the rights established on the intersecting parcels.

2.3.3 3D right-objects versus 3D physical objects

The solution of the registration of 3D physical objects requires considerable adjustments of the current cadastral registration system, technically as well as juridically [8][9]. Therefore in this research the focus will be on the registration of 3D right-objects. This solution requires little adjustment in the current cadastre registration (only an extension), furthermore the 3D right-objects are relatively easy to generate because the parcel boundaries are already available in the DBMS. On the other hand when 3D physical objects are registered, gaps in the cadastral registration can be traced (e.g. find which parcels intersect with the tunnel and do not have a right established for the tunnel).

The way 3D physical objects can spatially be maintained in the DBMS remains a topic of interest, e.g. as a tool to derive the 3D right-objects. The solution of 3D right-objects was also seen as the most optimal solution when looking at the current cadastral model (figure 1) and the juridical objectives of the Kadaster as was concluded in a meeting on April 11th, 2002 at the Kadaster.

2.4 Implementation

2.4.1 3D objects in the geo-DBMS

The concept of a 3D cadastre had to be translated into prototype implementations, which means maintaining 3D objects (3D right-objects or 3D physical objects) in the current cadastral geo-DBMS. Possible solutions were studied to maintain 3D objects in a geo-DBMS [10] [15]. Based on this study we started to model 3D objects in the DBMS within current techniques. 3D objects are herein defined as polyhedrons (3D body with flat faces). Using more complex geometries to define 3D objects (cylindrical and spherical patches) have turned out to be too complex [13] [14]. Furthermore, the 3D objects relevant for a 3D cadastre can be approximated adequately with a polyhedron approach. Two datamodels have been used for the representation of 3D objects in the DBMS: a geometrical model and a topological model [7] [8] [14]. For the implementation

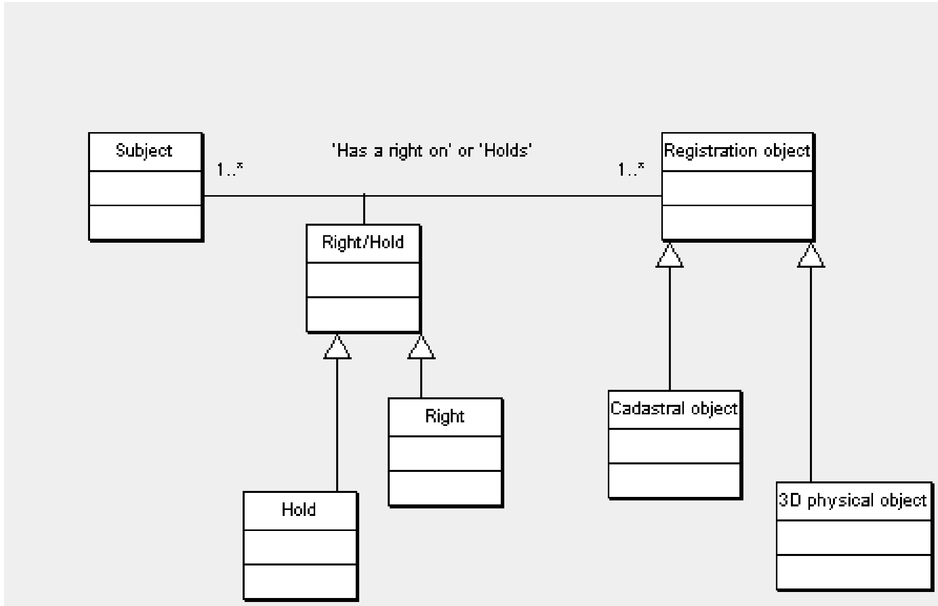

Figure 3: UML model of the current cadastre extended with the registration of 3D physical objects

Oracle Spatial 9i is used.

2.4.2 Generating parcel geometry

3D right-objects are defined by means of the parcel boundaries. Therefore the geometry of the parcels is needed. The geometry of parcels is also needed to find the intersection between a 3D physical object and parcels. In the current cadastral DBMS parcel boundaries are maintained geometrically while parcels are maintained topologically by means of references to the boundaries based on the winged edge structure. A function was written to generate (realise) the geometry of parcels within the DBMS [17].

2.4.3 Generating 3D right-objects

To describe 3D right-objects, a table has been introduced that contains for every parcel concerning a complex situation the different height-levels of (factual) ownership (z-list). The z-list contains n z-values corresponding to n-1 consecutive ranges associated with the parcel. In this way n+1 right-objects exist on one parcel, including the upper and lower open right-objects. Redundancy is avoided since only the z-levels are stored in addition to the currently stored data (boundary of parcels). This information is sufficient to generate the representation of 3D right-objects based on the realised geometry of the parcels. For this moment the height-levels are invariant for every 3D right-object, which means that the upper and lower boundaries of 3D right-objects are defined by horizontal planes. A function has been written to generate the representation of 3D right-objects (both using a geometrical model and a topological model). The implementation is illustrated in figure 4 for the HSL railway tunnel.

The 3D right-objects get a unique id. The (horizontal) limits of the 3D right-objects can

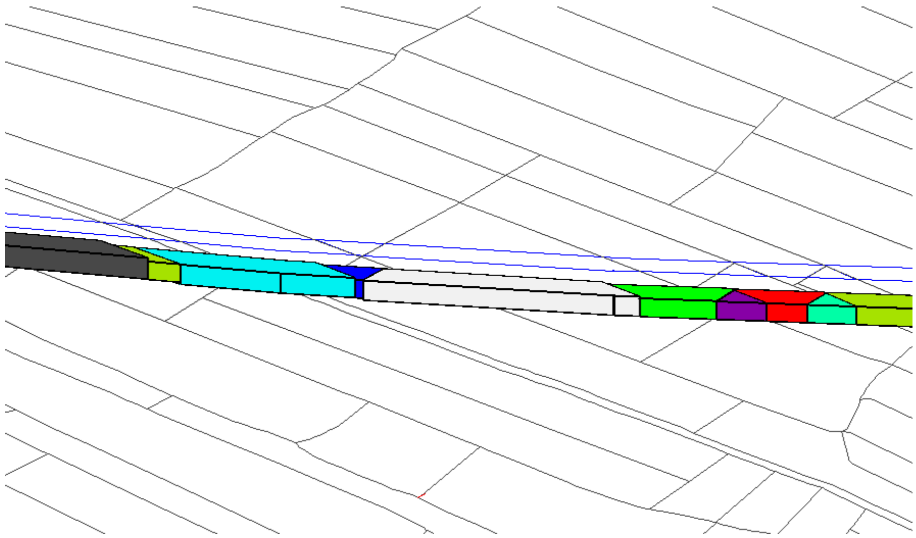

Figure 4: 3D right-objects of the HSL as generated in the cadastral DBMS. The projection of the tunnel on the surface level is also shown. The 2D boundary of the 3D right-objects are the intersections between de tunnel and the former parcel boundaries.

be related to the construction as built (the physical object). If the limits of the rights are defined in the deeds in the Public Registers these can be used to construct the 3D right-objects. In that case it can happen that the visualisation of the 3D right-objects is different than the actual built construction (e.g. when a right of superficies exceeds the actual construction).

2.4.4 Z-values of 3D objects: absolute or relative

A main issue still is the height that is assigned to the 3D object: an absolute value (in NAP) or relatively to the surface. A case study has been carried out to obtain height values based on the AHN *(Actueel Hoogtebestand Nederland)*. The AHN is a 2.5D surface of the Netherlands which has a density of at least one point per 16 square meters (with a validation accuracy of 5 cm). First height values from the AHN were assigned to parcel boundaries to be able to maintain 3D objects in absolute values. This was done by generating a TIN out of the AHN point data. And second the TIN was used to generate relative heights of a NAM pipeline since the absolute value of the depth of the pipeline was known and this could be combined with the height on the surface level on the location of the pipeline [11].

The generated TIN is topologically stored in the DBMS. The parcel boundaries were also added to the TIN in such a way that the parcel boundaries are triangle-edges in the TIN. In this way it is possible to select all triangles covering one parcel (triangles do not cross parcel boundaries) (see figure 5). This last model can help to construct a terrain elevation model of the 3D situation. Further research will focus on what is the most optimal way to maintain the z-values of 3D objects and parcel surface heights (see 3.3).

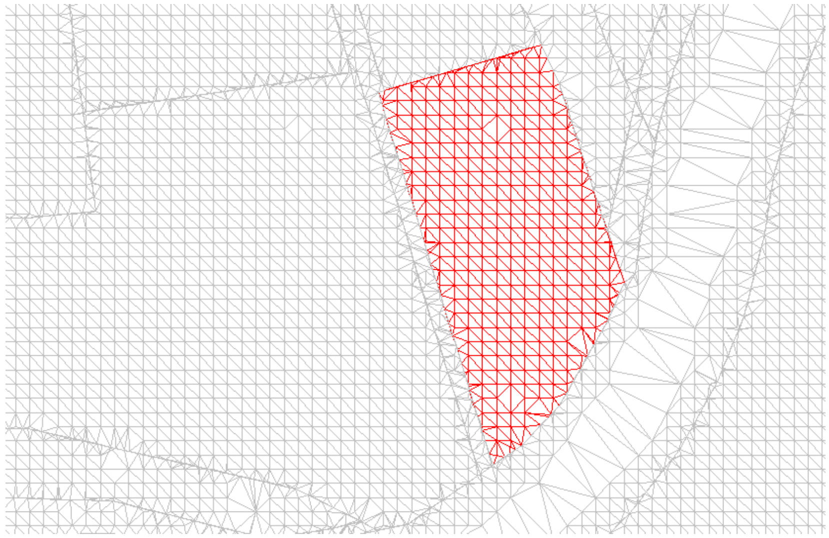

Figure 5: TIN generated from the points in the AHN and parcel boundaries . As you can see the triangles covering one parcel can be selected

2.5 Case studies

Till now, five cases from practice have been used to illustrate how current registration is carried out, to show complexities of current registrations and to test the implementations. These cases are:

- Nationale Nederlanden, Den Haag, building on top of a road [9] [15]
- Den Haag Centraal, building complex containing a railway station, a railway platform, a busstation, a tram station and a business centre [8]
- HSL tunnel, railway tunnel in the Green Heart of the Netherlands [4] [9]
- Two pipelines belonging to the NAM (results are not published yet)
- Apartment complex [8]

2.6 International trends

International developments on 3D cadastres have been studied. Therefore an international workshop on 3D cadastres was organised in Delft (November, 2001), in which eighty people from twenty-six countries participated. The international discussion on 3D cadastres was started during working sessions on juridical, technical and organisational aspects. A report of the working sessions (prepared by Elfriede Fendel) can be found on www.gdmc.nl/3DCadastres. Proceedings of this workshop [16] contain the papers that were presented during the workshop. The best papers were selected for a special issue of CEUS that is currently being published. The workshop had a continuation during the FIG congress 2002 in Washington by a special session on 3D cadastres. Also during this congress it was decided to start an international workgroup on 3D cadastres chaired by M.Salzmann from the Netherlands' Kadaster and Y.Doytsher from Technion Israel Institute of Technology. The working group will start this autumn and has a workplan till 2006. In [3] and [9] international trends on 3D cadastral registration are described.

At the European level the third meeting of COST G9 was organised in Delft (October 2002). The topic of this meeting was: towards a cadastral core domain model. A UML model for the registration of 3D situations was presented at this meeting [4].

2.7 3D CAD models

3D data is needed to represent 3D objects. Since 3D data is available with designers, mostly as CAD models, the idea was to examine how this information can be used and what selections and generalisations are needed to obtain the relevant information such as the outer boundary of objects. Municipalities, the Ministry of Transport and Public Works, and designers were visited in the search for usable CAD models. Based on this search the conclusion can be drawn that CAD models suitable for the 3D cadastre cannot or hardly be found. The main reason for this is that 3D physical objects are still designed on 2D drawings by using linear profiles and cross sections (figure 6). Contractors and builders are used to the 2D drawings: understanding 3D drawings would require special skills. The 2D models could be used to construct 3D models that are relevant for the cadastre (as this is the most original source). Therefore apart from the linear profiles and cross sections, also the trace of the tunnel is needed. In this process attention has to be paid to conversion of local coordinates to absolute coordinates in the national ordnance datum (RD for x,y and NAP for z).

In the design process 3D CAD models are generated from the designs for visualisation purposes. Also those models cannot be used for the 3D cadastre. The files can get unworkable large, since mostly they are not made for interactive purposes but to generate movies out of them. Furthermore they contain too much detail, objects can hardly be recognised in the file-based models and finally 3D spatial data in CAD contain complex geometries and are mostly parametrically described. At the moment these data cannot automatically be converted to the primitives that are available in spatial DBMSs (point, lines, polygons, polyhedrons). Also once the 3D objects are available as primitives in the DBMS 3D generalisation and simplification is needed to obtain the appropriate information.

Although the use of CAD models (2D and 3D) still seems to offer a lot of potentials for the 3D cadastre (information on the third dimension is available in those models), generating relevant information out of these models requires further study. The main reason for this is that experiences has shown that it is a very complex process to obtain the needed information out of these models. This requires an extensive study on basic fundamentals in GIS science (converting parametrically described geometry to geometry primitives and generalisation). To illustrate and underline this a MSc student is currently carrying out a case study to convert a 3D CAD model of a cycle-tunnel in Houten to a set of geometry objects representing 3D physical objects that can be stored as 3D geometries in the geo-DBMS (figure 7).

2.8 Used tools

The research is carried out in the scope of the GDMC (Geo-Database Management Center). This is the research and development center for all activities related to the mod-

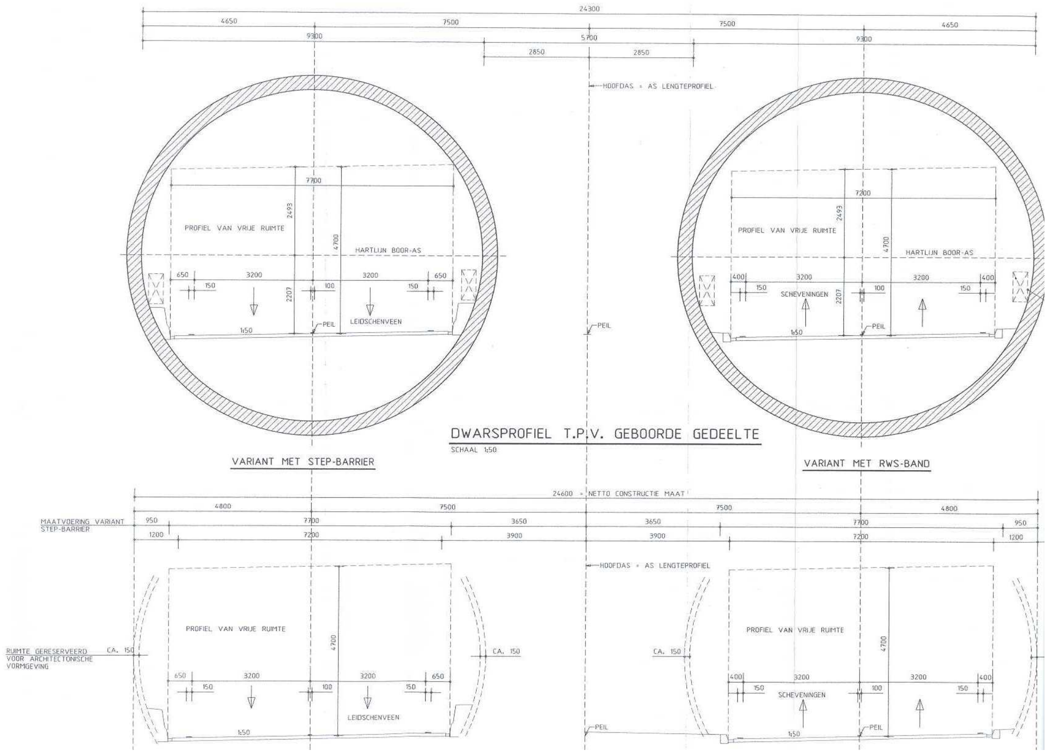

Figure 6: The CAD model designed for the 'Hubertus Tunnel' in the Hague

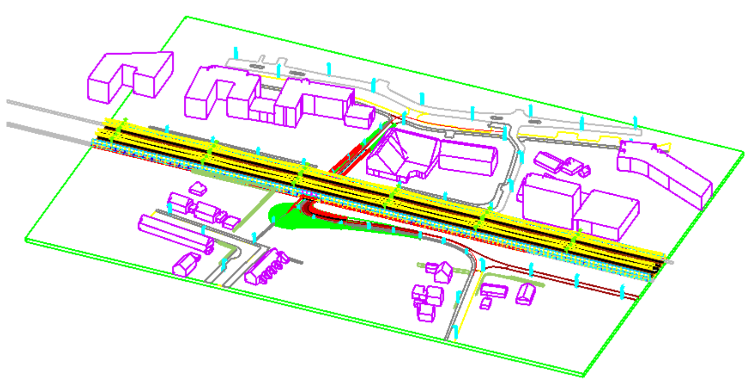

Figure 7: The CAD model designed for a cycle tunnel in Houten

elling, storage, retrieval, analysis and distribution of geo-information. At this moment the participants in the GDMC are Sun Microsystems, Oracle, Computer Associates (CA), Professional Geo Systems, ESRI and Bently. This means that we can use the software of those vendors, but also that we can collaborate and discuss with the development teams of the vendors. Concerning the 3D cadastre research we are working with the following tools:

- Oracle Spatial 9i for maintaining the 2D and 3D spatial information and the related attribute information
- Oracle PL/SQL to write functions in Oracle
- ArcGIS to visualise the 2D and 3D data stored in the DBMS
- MicroStation GeoGraphics to visualise and edit the 2D and 3D data stored in the DBMS
- ArgoUML to generate the UML models
- A tool developed by Ben Gorte (a colleague at Geodesy) to generate TINs

3 Planned activities November 2002-June 2004

The end of this study will be June 2004. The activities that are planned for the coming next two years are described in this section.

3.1 Improve the concept of 3D right-objects

A more clear and unambiguous definition of 3D right-object has to be developed. Questions that have to be answered are: what is the starting 2D boundary of a 3D right-object; are flat planes for the upper and lower boundaries of 3D right-objects sufficient or is more detail needed? Will apartments be treated as 3D right-objects? Apartments are special in the sense that the (property) rights in 2D can apply to just a part of the parcel: these 2D boundaries must then be included on the cadastral map.

3.2 Cases

The implementation will be tested on the described cases (see 2.5). Also more cases will be included. For example a situation in which the reference level varies across the parcel (e.g. a two floor building with at the for-entrance the first floor at street level and at the back-entrance the second floor at street level), or a situation in which horizontal boundaries of 3D right-objects may yield complications (e.g. a pipeline and a tunnel crossing one parcel). Based on these experiences the implementation as well as the developed concept can be improved.

3.3 Definition of height

Further research will focus on how to define the heights of 3D right-objects properly: using absolute or relative values. An absolute z-value for the definition of 3D right-objects is expected to be the most sustainable solution. The reasons for this are:

- the definition of the surface-level is sometimes unclear (think of modern architecture) and the solution of absolute z-values does not suffer because of this.
- absolute z-values are not dependent on the changes in surface level due to subsidence
- changes in the environment by human beings does not effect the definition of the 3D right-objects in case of absolute z-values

To be able to locate the 3D right-objects with respect to the surface level, a 3D view on the 2D parcels is needed. This means that the terrain-surface of elevation will be stored separately. The current parcels will still be stored as 2D parcels. It will be studied if it is possible to generate a good 3D view on the (2D) parcels and to add 3D right-objects (in absolute values) to this view together with the terrain elevation model.

3.4 Implementation of true 3D data types in the DBMS

A true 3D data type (with a volume) is not yet supported in DBMSs but included in the ISO standards. Therefore we have written a proposal to extend the spatial model of Oracle with support of a 3D primitive: the polyhedron primitive [11] [12] [13] [14]. The ideas behind the proposal are generic and can be applied to several DBMSs. The proposal is currently implemented, together with 3D functions on this 3D data type (validate functions, topological and geometrical functions in 3D).

3.5 Topology in DBMSs

At the moment we use user-defined topological models in the DBMS as in LKI together with functions we wrote ourselves to generate the needed geometry (both in 2D and 3D) [17]. Recently topology in DBMSs in 2D has become available in a commercial package. Therefore we will have a look at this possibility (Laser-Scan Radius based on Oracle Spatial). Also developments are going on at the front end. MicroStation GeoGraphics v8 has a GeoParcel module in which topology of parcels can be stored and recalled. We will also have a look at this module.

3.6 Using VRML and X3D to visualise and query the data

Till now MicroStation GeoGraphics is used to visualise the data that is maintained and generated in the DBMS. Although this has yielded good results, a less complex and better accessible environment is desired to visualise the data relevant for the 3D cadastre. Also in MicroStation Geographics it is hard to visualise attribute data. We work together with Bentley and therefore we are providing specifications of the needed functionalities to them. This could lead to building a prototype together.

VRML (Virtual Reality Modelling Language) is a language to describe 3D models and to make them accessible on the Internet. It is an open standard and can be used without licenses. Interaction and visualisation is done by plugins for web browsers (e.g. Cosmoplayer). Combined 2D and 3D information can be viewed in VRML (see figure 8). It will be examined if and in what way VRML can be used to query the needed information (parcels and 3D right-objects/physical objects) stored in the DBMS. The

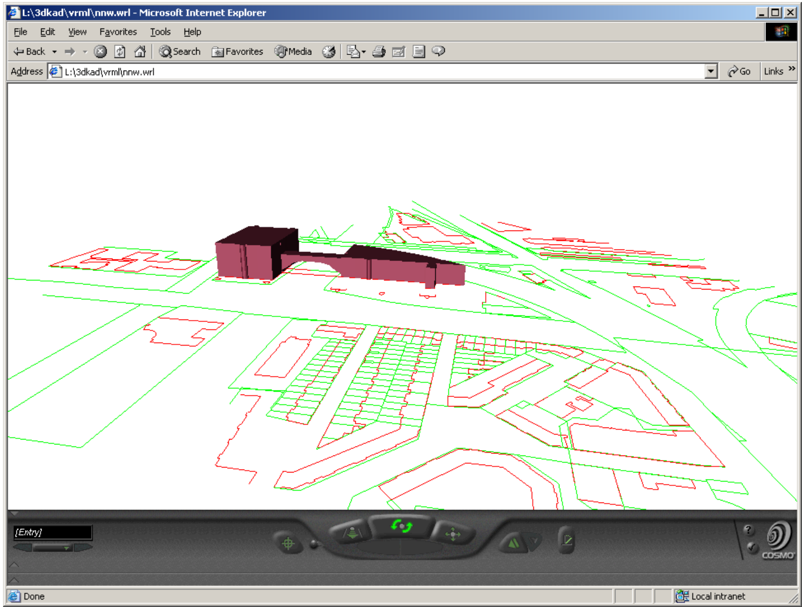

Figure 8: Data in the DBMS is converted to VRML to be able to view it with a web browser

querying/visualisation will be carried out in three steps. First the user has to specify the spatial selection and the query to indicate the area and the attributes where he is interested in. Based on these specifications a VRML file will be generated out of the DBMS with the needed information. Finally the information will be made available for the internet.

X3D (extensible 3D graphics) is the XML version of VRML. Since this is the successor of VRML, we will also have a closer look at X3D.

3.7 International visits

In the implementation phase of this research, we collaborate internationally with organisations that carry out similar research. Therefore one or two visits are planned to be able to work more closely together. Two potential organisations are:

- Centre for 3D geoinformation, Aalborg, Denmark. This centre was opened November 2001 and carries out research in the area of virtual reality and 3D modelling of urban and rural areas
- Bentley developing team. Bentley has a powerful module to handle geometry and topology of parcels (GeoParcel module). This might be worth visiting the developing team in the USA and work together on a 3D GeoParcel module.

3.8 Writing dissertation

An important part of the research is of course the actual writing of the dissertation. The proposed content of the dissertation is found in the next section.

4 Content dissertation

1. **Introduction**
   (1) 3D cadastre: Problem area
   (2) Research scope and objectives
   (3) Previous and related work
   (4) Previous and related work
   (5) Topics outside the scope of this work
   (6) Organisation of the thesis

   PART 1: ANALYSIS OF THE BACKGROUND

2. **3D cadastres abroad**
   (1) Examples of todays' solutions
   (2) Coming solutions
   (3) Research in progress

3. **Current cadastral registration in the Netherlands**
   (1) Public Registers and the cadastral registration system
   (2) Right of property
   (3) Cadastral model (object-right-subject)
   (4) 3D registrations and Private Law
   (5) 3D registrations and Administrative Law
   (6) Conclusions

4. **Current practice of current registration: Case studies**
   (1) Building on top of a road
   (2) Building complex
   (3) Railway tunnel
   (4) Two pipelines
   (5) Apartment complex
   (6) Concluding remarks on complexity of current registration

5. **Modelling**
   (1) Models: Objects, attributes, methods, relationships, constraints
   (2) Design phases in modelling
      1. Conceptual design
      2. Logical design
      3. Physical design

(3) Database Models
   1. The relational model
   2. The object-oriented model
   3. The object-relational model

(4) UML

6. **2D/3D GIS and DBMSs**

(1) 3D GIS

(2) Spatial objects in DBMSs
   1. Storage (geometry and topology)
      A. 2D
      B. 3D
   2. Spatial analyses (geometrical and topological)
      A. 2D
      B. 3D

(3) Connecting the DBMS to CAD/GIS
   1. Visualising/querying spatial data stored in the DBMS
   2. Editing spatial data stored in the DBMS

(4) Using VRML and X3D for visualising and querying 3D data

PART 2: TOWARDS A CONCEPTUAL SCHEMA FOR A 3D CADASTRE

7. **Conceptual datamodel for a 3D cadastre**

(1) Full 3D cadastre

(2) Hybrid solution

(3) 2D cadastre with references to 3D situations

(4) Solutions seen from a cadastral point of view

(5) Solutions seen from a technical point of view

(6) Conclusion

8. **A UML description of a 3D cadastre**

(1) Hybrid solution
   1. 3D right-objects
   2. 3D physical objects

(2) Conclusion

PART 3: REALISATION OF A 3D CADASTRE

9. **Logical and physical datamodel for a 3D cadastre**

(1) Spatial model of parcels in the cadastral DBMS

(2) 3D physical objects in the DBMS
   1. Using CAD data to obtain 3D geometry objects
(3) 3D right-objects in the DBMS
   1. Using a geometrical model
   2. Using a topological model
(4) Attributes and constraints of 3D right-objects
(5) Relationships between parcels and 3D right-objects
(6) Extension of spatial model in Oracle to support 3D objects
(7) Clustering, primary storage, indexing, topology management, Abstract Data Types
(8) Conclusion

10. **Combining 2D parcels and 3D objects in one environment**

(1) Definition of height
   1. Using absolute values
   2. Using relative values
(2) The terrain elevation model in the DBMS
(3) Generating height information based on the AHN
   1. Height of parcel boundaries and interiors
   2. Heights of 3D objects
(4) 2D parcels, 3D objects and the terrain elevation model in one 3D view
(5) Conclusion

11. **Implementation**

(1) Prototype system
(2) Case study: Building on top of a road
(3) Case study: Building complex
(4) Case study: Railway tunnel
(5) Case study: Two pipelines
(6) Case study: Apartment complex
(7) Conclusion

PART 4: CONCLUSION

12. **Conclusions and future research**

(1) Summary
(2) Outcomes
(3) Conclusions
(4) Future research

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