Cadastral Registration of Real Estate Objects in Three Dimension

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Abstract: *Cadastral registration of rights and limited rights is traditionally based on parcels that are represented in two dimensions. In intensively used areas, there is a growing interest in having separate ownership of space above and under the surface. It is difficult to reflect the spatial aspect of such rights in current cadastral registration systems. This article describes the development of a prototype registration system that accommodates spatial information in the vertical dimension.*

The three-dimensional cadastre conceptual development meets the needs of clearly defining ownership while taking advantage of new technical opportunities. The concept is illustrated through a prototype implementation and is an extension of the current cadastral registration system based on two-dimensional parcels. The approach shows substantial potential for improving understanding of complex cadastral situations.

Introduction

In major urban centres (and especially the business districts), land use is becoming so intense that very different types of "land" use (or more general "space" use) are being positioned under and above each other. Even though the creation of property rights to match these developments is available within existing legislation, describing and depicting them in cadastral registration systems creates a challenge.

This is not surprising when looking at the Fédération International des Géomètres (1995) description of a cadastre, which focuses on the cadastre being "a parcel-based, and up-to-date land information system containing records of interests in land (rights, restrictions and responsibilities)." When thinking about a parcel, most of us see it as being described by two-dimensional boundaries on the earth's surface. However, that does not satisfy the needs for more complex multi-layer property situations.

The Netherlands' Kadaster is responsible for the registration of parcel boundaries (cadastral map) and the legal status of parcels (land registry). For this purpose, it maintains a cadastral registration system that gives insight into the rights registered in deeds that are recorded in Public Registers. The cadastral registration system consists of: 1) a 2D geo-data base management system (DBMS) for maintaining the geometry and topology of parcels (and buildings for reference purposes) called LKI ("Information System for Surveying and Mapping"); and 2) an administrative DBMS for legal and other administrative data related to parcels called AKR ("Automated Cadastral Registration") (Lemmen et al. 1998).

In this article, both "cadastre" and "cadastral registration system" refer to this system. Using this system, the entire country is divided into parcels. The current cadastral registration is based on the property relations in a column: the 2D parcel on the surface is the entrance for registration. The vertical dimension of the legal status, which may be important, is not reflected in the spatial information system and can therefore only be registered administratively. The registration of the legal status of parcels is the only registration of real estate objects in the Netherlands. Building registration does not exist, although research is currently being carried out to establish such a registration (Kap and Zevenbergen 2000).

With a growing interest in using space under and above the surface, the vertical dimension becomes relevant in cadastral registration. Until now, three-dimensional situations can be registered within the current cadastral registration system in a juridical satisfying way. However, to guarantee an efficient, sustainable, and uniform registration in the future, the Kadaster decided to carry out a research project on the 3D aspects of cadastral registration. The project focuses on the extension of the current cadastral system to reflect the spatial component of rights in complex situations. The research project is carried out at the Research Institute for Housing, Urban, and Mobility Studies, Delft University of Technology, in collaboration with the Netherlands' Kadaster. During the research, a prototype of a land information system is being developed, which can take the relevant spatial information in the vertical dimension into account.

This article starts with a description of the current practice of registration of 3D situations and the accompanying complications. We describe a 3D cadastre that addresses these complications, as well as a prototype implementation.

Current Cadastre and 3D Situations

Situations in Practice with a 3D Component

The 3D situations in our research are complex registrations in the sense that they refer to situations with one parcel and several users (full owners and/or holders of limited real rights), each holding a right that is limited in space and positioned on top of each other. Examples of these complex situations are:

- constructions on top of each other (e.g., an underground garage);
- super- and subterranean infrastructure (e.g., a tram above the surface, tunnel, metro);
- apartments;
- the location and ownership of cables and pipes;
- historical monuments; and
- polluted areas.

What all of these situations have in common is that the third dimension is relevant in registering the legal status. Apart from apartments, there are no formal rules for registering the legal status, the geographical location (2D or 3D), or the extent of these 3D physical objects.

Current Registration Solutions in the Netherlands

At the current time, the situations mentioned in the previous paragraph are registered at the Netherlands' Kadaster by using ad hoc approaches within the current registry.

The solutions have in common that they are all administrative solutions, reducing the 3D situations to a definition in 2D by projecting them on the existing 2D parcels. According to the Dutch Civil Code (1992), the right of property of a parcel is not limited in the vertical dimension and hence property extends to the centre of the earth and into the sky. The right of property comprises the ability to be the exclusive user of the land (and space) owned. However, third parties are allowed to use the space above and below the surface as long as this is done as high or as low, and that the owner cannot reasonably object to this use. A horizontal division in the legal status of property is made by the establishment and registration of rights and limited rights on the parcels. This division does not contain explicit height values.

In the current cadastral registration system, with regard to land-related properties, a cadastral object is a complete parcel or a condominium right. A physical 3D object itself cannot be defined as a cadastral object and cannot be used as a base for registration. The only physical objects visible on the cadastral map are the outlines of buildings, which serve as a frame of reference for the parcel boundaries. The current registration practice of a complex situation is explained using the example of a building above a road (Figure 1).

Figure 2 shows a cadastral map containing parcels and buildings; in this map, three parcels are needed to register the

Figure 1: Example of a complex situation: a building above a road

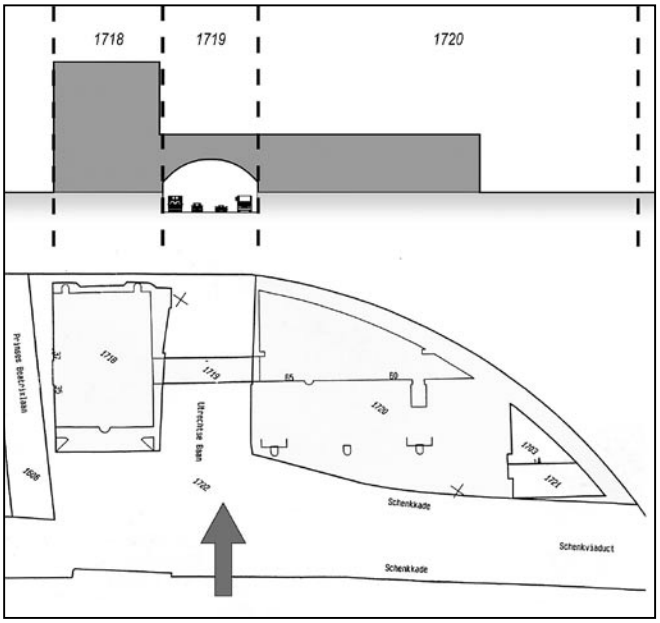

Figure 2: Cadastral map of the construction above the surface (arrow indicates the view position in Figure 1)

legal status of the building. This illustration shows how property relations in the vertical dimension are registered based on the division of the world into 2D parcels. The firm "Ing Vastgoed Belegging BV" is the owner of the entire building. The rights and restrictions of the parcels concerned are as follows: Municipality possesses a restricted right of property on parcels 1719 and 1720. Ing Vastgoed Belegging BV possesses an unrestricted right of property on parcel 1718, a right of superficies on parcel 1719, and a right of long lease on parcel 1720.

As far as private law is concerned, registrations of the legal status of parcels in which the third dimension might be relevant are (the Dutch terms are added in italics) (Stoter 2000):

- the right of property *(eigendomsrecht);*
- limited property rights *(privaatrechtelijke beperkingen):*
  - the right of superficies (i.e., the right to erect buildings under, on, or above land owned by a third party) *(opstalrecht);*

- the right of long lease (i.e., a third party gets the right to use the parcel (including space under and above the parcel) as if they are the owner) *(erfpacht);*
- the right of easement (i.e., a third party gets the right to use the parcel for a certain limited purpose) *(erfdienstbaarheid);*

- the right of condominium *(appartementsrecht);* and
- the right of joint ownership (i.e., shared ownership of an immovable good from which all shared owners of the parcels benefit; for example, walls, roads, parking places, and swimming pools) *(mandeligheid).*

Apart from the registered legal status, there are also non-registered 3D situations that deal with private law, such as horizontal accession *(horizontale natrekking)* or a non-registered toleration (e.g., a cable or pipe in the ground owned by the government).

Registrations of restrictions dictated by administrative law *(publiekrechtelijke beperkingen)* with a possible 3D component are:

- registration of the obligation to the owner of land to tolerate construction for public good, such as lampposts, electrical cables, water pipes, and telecommunication pipes *(belemmeringenwet privaatrecht);*
- deprival of minerals in the ground of the land owner *(mijnwet);*
- registration to protect historical monuments *(monumentwet);* and
- registration of severe soil pollution *(wet bodembescherming).*

In all of these cases, the parcels are affected with a restriction on the right of property. These restrictions are registered and not the factual objects that cause the restriction (cable, pipe, historical monument, etc.).

Complications of the Current Registration Solutions in the Netherlands

Complications encountered with the registration of 3D situations in a land information system that was originally developed to register 2D parcels are the following (Stoter 2000):

- the accessibility of the registration in 3D situations is not optimal because no digital 3D representation is available;
- rights are used in situations for which they were not originally meant (condominium right for a parking place); and
- different ad hoc solutions are used for the registration of comparable 3D situations.

Only the parcel is registered, not the object on, above, or below the surface. This means that the physical objects for which the legal status must be registered are not registered as such by the Kadaster. This leads to the following complications:

- the physical object itself or characteristics of the object are not maintained and therefore cannot be queried at the Kadaster (with the exception of the footprint of buildings for reference purpose): queries such as "who is the owner of this tunnel" or "I know there is a pipeline somewhere down here, but is it under the parcel that I am interested in" cannot be performed;
- constructions are illogically divided into parts in order to let them match with the surface parcels;
- it is necessary to store the information associated with the construction at every parcel that intersects with the object (e.g., a cable for which restrictions need to be registered under several parcels): this leads to redundant information that may result in inconsistencies; and
- the database becomes polluted when parcels are subdivided, since only the parcels that intersect with the object are known and not the exact location of the object. After subdivision, it is not clear which newly formed parcels should be marked.

A 2D representation of physical objects in the cadastral DBMS would help resolve the complications listed above to a considerable extent because: 1) the information could be coupled to the physical object without redundancy instead of repeating this information for every parcel crossed; and 2) when a parcel is subdivided, it can be determined which of the newly formed parcels should be marked using the geometry of the physical object.

These complications show the limitations of the current cadastre in the case of complex situations. The main problem is that the relevant information is not available and therefore not accessible in the cadastral registration system. Standardization of methods used to gain insight in the situation existing under and above the surface would increase legal security and ease the work of notaries and the Kadaster (i.e., fewer administrative "tricks" are needed). From a legal point of view, the Kadaster manages 3D situations adequately, but in an ad hoc fashion. We now present a 3D cadastre that supports a sustainable, efficient, and uniform registration of 3D situations. The concept of a 3D cadastre is based on these considerations.

A 3D Cadastre

The Alternatives

Three alternatives were considered (Stoter, J.E. and P.J.M. van Oosterom 2002):

1) *A Full 3D Cadastre:* The 3D space (universe) is partitioned into volumes (or 3D parcels) without overlaps or gaps. With this, the concept of property rights in 3D space is introduced. The legal basis, real estate transaction protocols, and the cadastral registration should support the establishment and conveyance of 3D rights. From a practical point of view, it seems best to maintain the 2D parcel as default (with an implicit third dimension) and to use the full 3D parcel only in complex 3D situations.
2) *A Hybrid Solution:* Preservation of the 2D cadastre and registration of the situation in 3D by registering 3D physical

objects within the 2D cadastral registration when there is a legal reason to do so. This results in a hybrid solution of the registration of 2D parcels (which is a legal registration) and the registration of 3D physical objects (which is a registration of factual objects). Explicit relationships between the parcels and the 3D physical objects are also maintained. Implicit relationships exist through the spatial definition of the objects and can be retrieved by spatial functions.

3) *2D Classical Registration with References:* Preservation of the 2D cadastre with external references to representations of 3D situations. Complex 3D situations are registered using ad hoc solutions. The reference can be implemented in various ways. The simplest solution is to tag 3D situations in the registration so that the Public Registers can be consulted for detailed information (e.g., a computer-assisted drawing). A more advanced option is to add a reference to a 3D description within the registration.

Preferred Alternative

In Stoter and Salzmann (2001), we looked for the requirements of a 3D cadastre both from a cadastral and a technical viewpoint. We concluded that for the long-term future a full 3D cadastre is the preferred alternative, but that for the medium-long term future the hybrid approach is the most optimal choice. Concerning the cadastral point of view, the Kadaster has to be able to visualise the established rights that are recorded in the Public Registers. Therefore, the Kadaster wants to assure that complex situations are registered correctly and that the registration provides insight into the actual (legal) situation in a simple, straightforward, and sustainable manner. A full 3D cadastre is too complex because it would require complete renewal of the cadastral registration. To introduce rights defined in 3D, a change in the Civil Code is necessary, and this is a lengthy process. In the hybrid solution, 2D and 3D information are both available and can be combined. This offers improvements from the point of accessibility compared to the current 2D classical registration in which 3D situations are tagged.

From a technical viewpoint, the hybrid approach can still make use of the current registration possibilities and of the 2D data that are already available in large amounts. For a full 3D cadastre, 3D support of both geometry and topology is necessary in DBMSs, and this does not exist yet. As discussed above, 2D classical registration is limited in its ability to handle future situations. For the hybrid approach, we can make use of current techniques for spatial support in DBMSs. We have therefore implemented a hybrid approach, which extends the current registration of 2D parcels with the ability to register 3D situations.

Implementation of the Hybrid 2D/3D Cadastre Concept

A prototype implementation was developed to serve as a trial to the hybrid approach. The geo-DBMS in which the 2D parcels are maintained is the starting point. For the implementation, Oracle Spatial 9i is used (Oracle 2000). Current mainstream DBMSs, including Oracle, do not support 3D volumetric data types. Stoter and van Oosterom (2002) have proposed an extension of the spatial data model of Oracle with support for polyhedrons (3D bodies described by flat faces). In the meantime, we use the currently available data types: points, lines, and polygons, which can also be defined in 3D in the DBMS. We define a 3D spatial object by means of a conceptual polyhedron primitive. The flat faces can be represented as 3D polygons in Oracle. A 3D geo-object can now be defined either as a complex object consisting of a set of 3D (flat) polygons (i.e., several records are needed to define the polyhedron) or as one 3D multi-polygon (i.e., one record is needed). In the prototype, the support for 3D spatial objects was implemented in two ways: using spatial data types, and using a topological model. A topological model is needed to improve querying and to check consistency during updates. Since topology is not yet supported in DBMSs, we implemented a user-defined topological model. We also used spatial data types so that it would be possible to utilize currently available techniques.

There are two possibilities in which to register 2D parcels and 3D situations in one system. The least complex possibility is to register rights concerning 3D situations in 3D. A more advanced solution is to register 3D physical objects apart from 2D parcels. In this section, we describe the two types of registrations and how they are implemented in the prototype. The data models for these registrations, including the 3D models, are then explained. In the last part of this section, we discuss the integration of 3D geo-objects and the already available data in 2D parcels in one environment; in particular, how to position these two types of data in the vertical dimension with respect to each other.

Registration of 3D Right-Objects

A right can be associated with a 3D representation of a right (3D right-object). The boundary of this 3D representation starts with the parcel boundary and is extended into 3D by means of defining the upper and lower limits. When more detail is required (e.g., when only part of a parcel deals with a complex situation), a new parcel boundary needs to be generated (e.g., if a cable crosses only part of a parcel, a smaller parcel is created to depict the location of the cable more precisely). In the meantime, we are looking for possibilities to spatially define rights more precisely in 3D and 2D. This also will have juridical consequences.

The 3D right-objects that are maintained contain references to the entire spatial object, of which non-spatial and spatial characteristics may be stored in or outside the DBMS. All 3D right-objects belonging to one 3D physical object can be derived because they all refer to the same 3D physical object. The registration of a 3D physical object can consist of several rights belonging to this particular 3D physical object (e.g., right of superficies, condominium right, etc). You can then query which parcels contain a right or limited right related to a specific 3D physical object. To support this, a record with at least the identification (the "id") of this 3D physical object must be present

within the system. Currently, you cannot perform this query, as there are no physical objects available. The 3D extent of a right also cannot currently be queried (e.g., to what height or depth does the right of superficies extend?).

A 3D right-object associated with a right on a parcel is only registered when this is juridically required, which is the case in complex situations. In other cases, it is voluntary. For that reason, the entire 3D physical object does not need to be known in the cadastral registration system. It can happen that a 3D physical object (e.g., a tunnel) is registered for some surface parcels and not for others. This can be the case when the owner of the 3D physical object is the owner of the parcel. In those situations, the uniformity of the registrations can be at risk, and with this insight into the 3D situation. Ultimately, the choice of 3D registration is dependent on the subjective choice of parties, advised by their notary.

To describe rights regarding complex situations in 3D, we introduce a table that contains the different height-levels of ownership (z-list) for each parcel involved in a complex situation. 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 uppermost and lowermost (open) right-objects. Redundancy is avoided since only the z-levels are stored in addition to the currently stored data (the boundary of parcels). This information is sufficient to generate the representation of 3D right-objects based on the realized geometry of the parcels. For the current time, the height levels are invariable for each 3D right-object, which means that the upper and lower boundaries of 3D right-objects are defined by horizontal planes.

Figure 3 shows the result of implementing the registration of 3D right-objects applied to the case introduced earlier. Although the building itself is not registered, the 3D right-objects established for the building are registered, together with 3D representation (compare this with Figures 1 and 2). The data are maintained in the DBMS (Oracle) and visualized with MicroStation GeoGraphics (Bentley 2001). Figure 3 shows that the 2D extent of the 3D representations (footprint) is the same as the parcel boundaries.

The input table for the 3D right-objects is as follows:

```
SQL> select * from input_3d;

MUNICIPALITY  OSECTION    PARCEL   Z_LIST
------------  --------    ------   ------
GVH32         AP          1718     Z_ARRAY(0, 35) /* right of property
GVH32         AP          1719     Z_ARRAY(5, 21) /* right of superficies
GVH32         AP          1720     Z_ARRAY(0, 21) /* right of long lease
```

The right-object on parcel 1718 does not need to be created because the owner of the parcel is the same as the owner of the building. Based on this input table and the table that contains the geometry of parcels, the 3D right-objects can be generated.

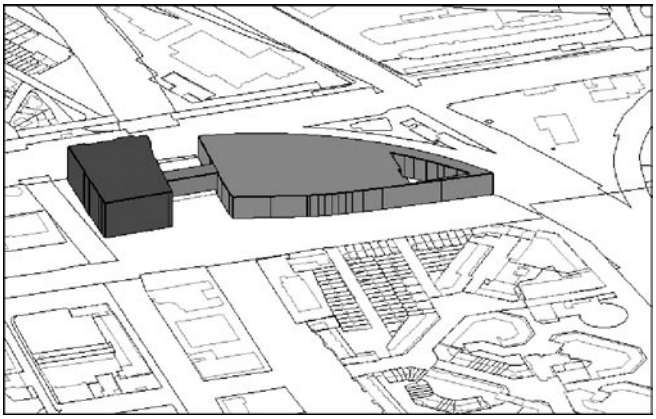

Figure 3: Registration of 3D right-objects: right of property on the left parcel, right of superficies on the middle parcel and right of long lease on the right parcel.

The 3D right-objects get a unique "id": the full parcel number followed by a z-index (0 for everything below the first value in the z-list, 1 for everything between first and second value in z-list, etc.). The ownership information can be found by finding the subject(s) that has (have) the right that is associated with the 3D right-object. The legal status of the space above and under the building complex is not explicitly registered. However, according to the legal rule, the owner of the parcel is owner of the space under the complex, and the subject who has a right of superficies on the parcel is owner of the space above the construction. The long leaseholder has the right to use the parcel including space under and above the parcel. In this case, the limits of the 3D right-objects are related to the construction as built. If the limits of the rights are defined in the deeds, these can be used to construct the 3D right-objects. In that case, it can happen that visualization of the 3D right-objects is different than the actually built construction (e.g., when a right of superficies exceeds the actual construction).

Registration of a 3D Physical Object

A more advanced method is to register the real-world objects themselves. This approach requires more drastic adjustments in the current cadastre, technically as well as juridically. In this case, the existence of a 3D physical object forms the base for registration. A registration of 3D physical objects needs to be organized and maintained, and this registration will become a cadastral task. To implement this registration, a finite list of the objects that need to be registered must be prepared. It must be decided whether this list can include "empty space" objects or not. This can be compared to similar international experiences: "air space parcels" are known in British Columbia (Gerremo and Hansson 1998), while "construction properties" in Norway (Onsrud 2001) and "3D property units" in Sweden (Julstad and Ericsson 2001) must consist of constructions actually built or planned to be built within a fixed time frame. The last two will get legal force in the coming years.

3D physical objects defined on the list must be registered. For registration to be indisputable, a law is needed to make the registration obligatory. In the registration system, spatial as well as non-spatial information on the entire 3D physical object are maintained. A 3D physical object can be queried as a whole. For example: Which parcels are intersecting with the projection of a 3D physical object? Which rights are established on these parcels? Who are the right-owners? These queries can also be performed when the whole 3D physical object is maintained as in the case of registration of 3D right-objects. The following query returns the rights and owners of rights on parcels intersecting with a 3D physical object:

```
-- which persons have which rights on the parcels intersection with
a railway tunnel?--
select r.municipality m, r.osection s, r.parcel_num p, r.kind_of_right
k, s.name n
from right r, subject s
where (municipality, osection, parcel_num) in
 (select municipality, osection, parcel_num
 from parcel, railwaytunnel t
  where  sdo_geom.relate(return_parcel(object_id),  'anyinteract',
t.shape,1) = 'TRUE')
and
 s.subject_id = r.subject_id;
```

The "return_polygon" function "realizes" the geometry of parcels (van Oosterom et al. 2002) based on the topology structure as stored in the parcel (face) and boundary (edge) tables. The current 2D cadastral model is based on a topology structure in which parcels are topologically maintained and the boundaries are geometrically maintained based on the winged-edge structure (van Oosterom and Lemmen 2001). It is possible to select parcels that overlap with the projection of a 3D physical object. For this purpose, the parcels must be "realized" first as polygons; with these polygons, the actual overlap computation with the tunnel polygon ("t.shape" in this case) can be performed.

Figure 4 shows the implementation of this registration applied to the previously introduced example. The spatial data are maintained in the DBMS. Apart from the parcels and outlines of buildings, the 3D physical object is maintained as one 3D multi-polygon, which is the 3D representation of the building.

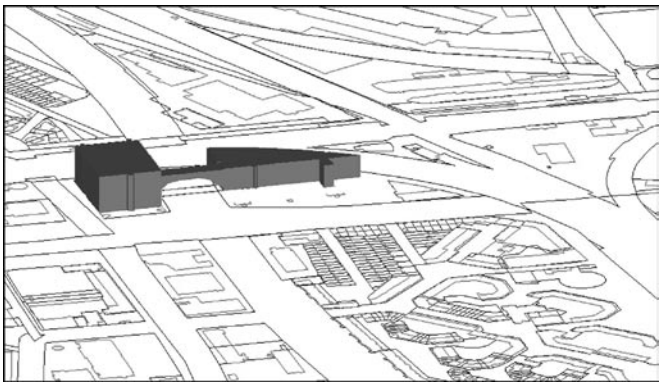

Figure 4: Registration of a 3D physical object (building on top of other properties)

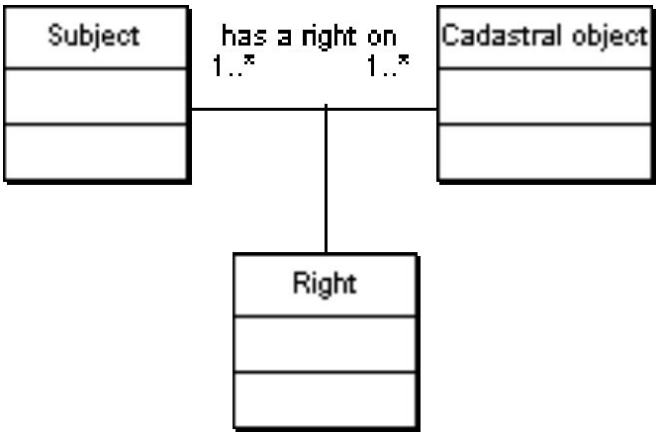

Figure 5A: Data model of the current cadastre

Data Models

Figure 5 shows the UML class diagrams of the cadastral data models, including 3D situations. The cadastral data model is based on three key entities: object, subject, and right (Figure 5A). A cadastral object is a parcel (and in some countries also a condominium right related to one or more ground parcels). Subjects are natural or non-natural persons with a right on a parcel. For every subject-object relationship, a right is registered in the cadastral registration system. Between objects and subjects, an n: m relationship exists via the right relationship; a subject can have a right related to more than one object (e.g., a person is owner of three parcels) and an object can have a relationship with more than one subject (e.g., one person has the right of property on a parcel and another person has the right of superficies on the same parcel).

For a full 3D cadastre, the same data model applies. However, cadastral objects are now defined in 3D (3D parcel), and rights (e.g., the right of long lease or the right of superficies) are related to 3D parcels. No relationship exists between the surface parcels and 3D physical objects, since 2D surface parcels do not exist. Apartments are cadastral objects, defined in 3D, on which a subject can have a right of property.

The data model for the registration of 3D right-objects is shown in Figure 5B. For every right that is established on a parcel and that concerns a complex situation, a 3D right-object is maintained. This contains the 3D representation of the right, which is also maintained in the DBMS via the z-list. Several 3D right-objects can be associated with one right (e.g., if a subject is holder of two tunnels intersecting with one parcel and one right of superficies is established on the parcel to hold the two tunnels).

All 3D right-objects belonging to one physical object can be found since they refer to the same 3D physical object. As can

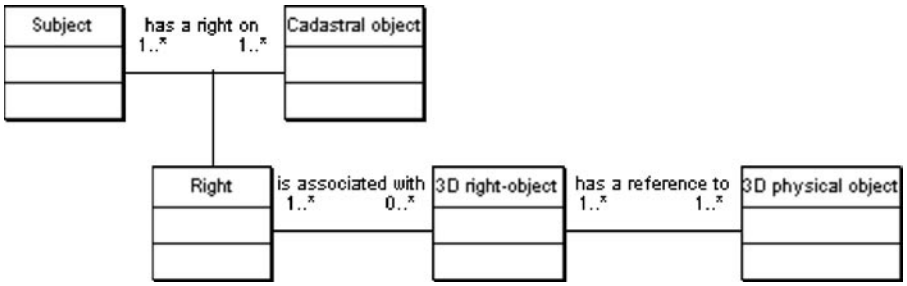

Figure 5B: Data model for the hybrid approach with registration of 3D right-objects

be seen, this data model (Figure 5B) needs some adjustment in the current data model (Figure 5A), but the principle of the 2D parcels as objects remains the same.

When registering 3D physical objects, the data model in Figure 5C applies. Apart from parcels (Object), 3D physical objects are also registered. The holder of the 3D physical object has rights to a 3D physical object (factual ownership, which is not the same as the juridical ownership). In general, the holder of a 3D physical object is the person or organization who is responsible for the 3D physical object and uses the object as if he/she were the owner. A 3D physical object is not a subset of a cadastral object, since 3D physical objects are maintained in addition to 2D parcels. Rights and limited rights are still registered on parcels. The only right that a person can obtain a 3D physical object is that he/she can become the holder of this object.

Since both the 3D physical object and the cadastral objects are spatially defined, the relationship between them can be obtained by means of spatial overlap functions and therefore this relationship does not need to be explicitly maintained. Juridical relationships between the 3D physical object and the parcels are not explicitly maintained. These relationships can be obtained by means of a common owner of the right: the subject who is holder of a 3D physical object is the same as the subject who should have some right on the surface parcel.

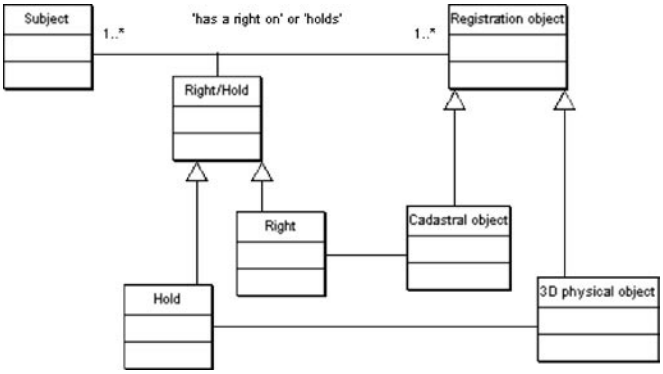

Figure 5C: Data model for the hybrid approach with registration of 3D physical objects

Inserting 3D Data into the 2D Geo-DBMS

To know where the 3D geo-objects are situated in relation to the surface, one has to know the "horizontal zero level" on which the 2D geo-objects are defined. With this, two possible representations of z-coordinates of the 3D geo-objects can be distinguished:

1. An absolute z-coordinate, defined in the national reference system: When z-coordinates of the 3D geo-objects are stored in a national reference system, the height of surface parcels is also needed to define geometrical and topological relationships between the 3D geo-objects and the 2D parcels (e.g., above, below, or intersecting). The collection and input of this additional information related to the existing 2D parcels will take considerable time. Moreover, the complexity of the 2D data increases, since 2D parcels need to be defined in 3D space. This cannot be done by simply adding one z-coordinate per parcel, since some parcels may contain too much spatial variance for this approach (even in a "flat" country like the Netherlands). As illustrated below, adding a z-value to the vertices describing parcel boundaries is not sufficient.
2. A relative z-coordinate, defined in relation to the surface: When z-coordinates defining 3D geo-objects are stored with respect to the surface, the current geo-DBMS does not need to be extended with additional z-information on current 2D geo-data, saving time and data complexity. The z-coordinates of the 3D geo-objects, known in the national reference system, must be converted to relative coordinates. In this case, only the 3D situation in the surrounding of the 3D geo-object needs to be explored, instead of locating all 2D geo-data in 3D space. Maintaining data consistency in case of updates might be hard (e.g., when the surface level changes) since a surface level change does not automatically lead to an update at the Kadaster. Another disadvantage of this solution is that 3D models might become ambiguous in the case of non-flat surfaces.

Example of How to Deal with the Z-Coordinate

In the Netherlands, a 2.5D surface is available for the entire country in the Actual Height model of the Netherlands (AHN),

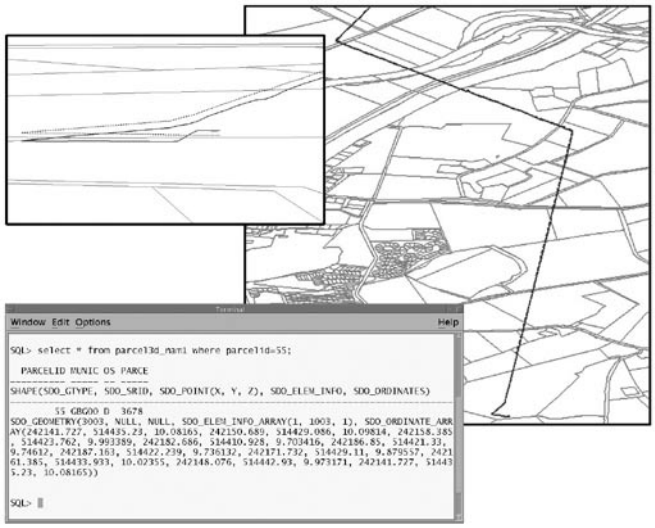

Figure 6: Parcels defined with x-, y-, z-coordinates in the DBMS combined with a pipeline also known in 3D. The inset is the enlargement of the end of the pipeline. The dashed line is the surface level on the location of the pipeline. The relative depth of the pipeline is hard to see, due to the fact that the boundaries of parcels are represented in 3D and not the surfaces of the parcels (see Figure 7).

x	y	z	surface	wrt_surface
242850.36	512938.67	10.44	9.177488	1.262512
242850.25	512938.80	10.34	9.17832	1.16168
242849.52	512939.37	10.35	9.181968	1.168032
242847.22	512941.22	10.34	9.17208	1.16792
242847.21	512941.25	10.38	9.172072	1.207928
242847.17	512941.25	10.38	9.171944	1.208056
242845.24	512942.82	10.38	9.165616	1.214384
242844.80	512943.11	10.23	9.163164	1.066836
242843.01	512944.55	8.89	9.165188	-0.275188
242841.22	512945.95	7.58	9.170208	-1.590208
242840.92	512946.21	7.42	9.170436	-1.750436
242840.47	512946.54	7.33	9.17049	-1.84049
242839.11	512947.64	7.32	9.170586	-1.850586
242835.29	512950.64	7.23	9.197065	-1.967065
242821.29	512962.05	7.17	9.140288	-1.970288
242820.76	512962.44	7.16	9.119136	-1.959136
242811.67	512969.86	6.93	8.96213	-2.03213
242807.54	512973.22	6.89	8.942776	-2.052776
242806.95	512973.71	6.87	8.941536	-2.071536
242806.38	512974.91	6.87	8.949648	-2.079648
242806.37	512974.91	6.88	8.949504	-2.069504
242806.71	512976.23	6.88	8.972352	-2.092352
242808.41	512978.28	6.92	8.995645	-2.075645
242809.12	512979.15	6.94	8.989553	-2.049553
242813.98	512985.07	7.01	8.977824	-1.967824
242820.15	512992.63	7.06	8.989792	-1.929792
242826.80	513000.78	7.07	9.005609	-1.935609
242834.26	513010.03	7.09	9.021051	-1.931051
242841.85	513019.50	7.04	8.98325	-1.94325
242849.28	513028.84	7.12	9.031892	-1.911892

Figure 7: Pipeline combined with the AHN (2.5D surface data) results in values at the surface level and values with respect to the surface level. Note that the first part of the pipeline is located above the surface.

which has a density of at least one point per 16 square meters with a validation accuracy of 5 cm (van Heerd et al. 2000). This 2.5D surface has been obtained by the use of airborne laser altimetry. These data can be used to position 3D geo-objects relative to the surface.

We tested assigning height data to vertices describing the parcel boundaries. The height data were generated from a TIN (Triangular Irregular Network) that was created with the height data points of the AHN (first option, the absolute z-coordinates) (see Figure 6). The NAM (Nederlandse Aardolie Maatschappij, equally owned by Shell and Exxon) provided the 3D data of two pipelines. As can be seen in Figure 6, the parcels defined by x-, y-, and z-coordinates are not sufficient to determine the location of the pipeline relative to the surface. To accurately capture the situation, data points on the parcels themselves are needed.

After retrieving heights at surface level on the location of the pipelines based on the AHN, the location of the pipelines relative to the surface could be determined without having information on the height of parcels (second option) (see Figure 7). In "flat" areas, this information gives insight into the location of the physical object. In non-flat areas, this information might become dubious: a z-value of 3 is not necessarily lower than a z-value of 6.

Concluding Remarks

A hybrid approach of registering 3D objects in addition to existing 2D parcels provides a promising medium-term solution for dealing with 3D situations. This solution gives insight into the 3D aspect of registered rights. The 3D right-objects are rights defined in 3D and based on the 2D parcels (e.g., a right of superficies that concerns a part of a building that is constructed above a road). The underlying principle of this approach is that the vertical division of a parcel-column fits the current method of cadastral registration, with the 2D parcel on the surface as a basis. A more advanced solution is to register 3D physical objects as they occur in reality (tunnel, complex building, etc.). Both approaches have been translated into prototype implementations to determine their advantages and disadvantages.

Since the registration of 3D right-objects requires the least adjustment in the current cadastral registration system while it considerably improves the insight into 3D situations, we first focus on this approach. Non-spatial, and possibly also 3D spatial, characteristics of the whole 3D physical object are thereby also maintained. The polyhedron primitive is used for both the realized spatial representation of 3D right-objects (based on the 2D parcel topology and the z-list) and the geometric representation of 3D physical objects.

The prototype implementations are being applied on cases from practice. During this process, we will improve and strengthen the developed concept of a 3D cadastre, as well as the implementations, to come to an optimal solution. In the mean time, we will continue to study and improve techniques for full 3D functionality in DBMSs (for both geometry and topology) in order to support the conceptually most elegant alternative, a full 3D cadastre.

Further Reading

In November 2001, an international workshop on 3D cadastres was organized in Delft. The proceedings of that workshop contain papers covering juridical, technical, and organizational aspects. The contributors were from Israel, Kenya, Slovenia, Finland, Norway, Canada, Greece, Iran, Germany, Denmark, Sweden, Belgium, Honk Kong, Czech Republic, Ukraine, Hungary, and the Netherlands (van Oosterom et al. 2001).

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References

Bentley MicroStation GeoGraphics ISpatial edition (J 7.2.x), 2001. http://www.bentley.com/

Civil Code (Burgerlijk Wetboek), 1992, Boek 5: Zakelijke Rechten, 1992. [In Dutch]

Fédération International des Géomètres, 1995, The FIG Statement on the Cadastre. Publication No. 11, 1995.

Gerremo and, J. and J. Hansson, 1998, Ownership and Real Property in British Colombia: A Legal Study. M.Sc. Thesis (nr. 48). Royal Institute of Technology, Stockholm, Department of Real Estate and Construction Management, Division of Real Estate Planning and Land Law.

Julstad, B. and A. Ericsson, 2001, Property Formation and Three-Dimensional Property Units in Sweden. International Workshop on 3D-Cadastres -Registration of Properties in Strata, Delft, November 28-30, 2001, FIG, Frederiksberg, Denmark, pp. 173-190. ISBN 87-90907-15-9.

Kap, A.P. and J.A. Zevenbergen, 2000, Valkuilen en kansen bij de opzet van landelijke registraties: Een (inter)nationale vergelijking. Technical Report. Department of Geodesy, Delft University of Technology, 2000. [In Dutch]

Lemmen, C.H.J., E.P. Oosterbroek and P.M.J. van Oosterom, 1998, New Spatial Data Management Developments in the Netherlands Cadastre. FIG XXI International Congress, Brighton UK, Commission 3, Land Information Systems, July 19-25, 1998, pp. 398-409.

Onsrud, H., 2001, Making Laws for 3D Cadastre in Norway. International Workshop on 3D-Cadastres -Registration of Properties in Strata, Delft, November 28-30, 2001, FIG, Frederiksberg, Denmark, pp.191-199. ISBN 87-90907-15-9.

Oracle, 2000, Oracle Spatial, User's Guide and Reference, Release 8.1.7, Part No. A77132-01.

Stoter, J.E., 2000, Needs, Possibilities and Constraints to Develop a 3D Cadastral Registration System. UDMS 2000 22nd Urban and Regional Data Management Symposium "Urban and Rural Data Management Common Problems - Common Solutions/Seminar Land Markets and Land Consolidation in Central Europe," Delft, the Netherlands, September 11-15, 2000.

Stoter, J.E. and M.A. Salzmann, 2001, Towards a 3D-Cadastre: Where Do Cadastral Needs and Technical Possibilities Meet? International Workshop on 3D-Cadastres -Registration of Properties in Strata, Delft, November 28-30, 2001, FIG, Frederiksberg, Denmark.

Stoter, J.E. and P.J.M. van Oosterom, 2002, Incorporating 3D Geo-Objects into a 2D Geo-DBMS, FIG XXII/ACSM-ASPRS, April 19-26, 2002, Washington.

van Heerd, R.M., E.A.C. Kuijlaars, M.P. Teeuw, and R.J. van't Zand, 2000, Productspecificatie AHN 2000, Rijkswaterstaat, Meetkundige Dienst, Rapportnummer: MDTGM 2000.13, 2000. [In Dutch]

van Oosterom, P.J.M. and C.H.J. Lemmen, 2001, Spatial Data Management on a Very Large Cadastral Database. Computers, Environments and Urban Systems (CEUS), 25(4-5), 509-528.

van Oosterom, P.J.M, J.E. Stoter, and E.M. Fendel (Eds.), 2001, International Workshop on 3D-Cadastres -Registration of Properties in Strata, Delft, November 28-30, 2001, FIG, Frederiksberg, Denmark. ISBN 87-90907-15-9.

van Oosterom., P.J.M., J.E. Stoter, S. Zlatanova, and W.C. Quak, 2002, The Balance Between Geometry and Topology. Spatial Data Handling, 2002 Symposium, Ottawa, Canada, July 9-12, 2002.