3D aspects of cadastral data modelling

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Abstract

Property rights on real estate are registered on cadastral parcels. These parcels are the result of a delimitation of the earth by boundaries projected on the surface.
The division of ownership of buildings and land in horizontal layers is possible by establishing a right of superficies (*opstalrecht*). The result is a horizontal subdivision by reference to depths or horizons, within one parcel.
In this paper we will elaborate on the 3D aspects that should be considered in the development of a generic cadastral data model.
To illustrate the 3D aspects, two cases are described: a building complex and a drilled tunnel in a rural area. Based on these cases, the complications of the current 2D approach in 3D situations are demonstrated. Two alternatives will be described to register 3D objects in the cadastral DBMS. For the midterm future the concept of 3D right-objects, introduced in the research '3D cadastre' (Stoter et al., 2002), can be a way to improve the current way of registration (Stoter and Ploeger, 2002), although 'gaps' (cases where the location of the construction in 2D and 3D is not known) may still occur. Therefore the registration of the legal space of 3D objects is a better solution for the long-term future.
The alternatives described in this paper should contribute to the awareness of 3D aspects in cadastral data modelling.

1. INTRODUCTION

The traditional cadastre is based on a division of land in 2D parcels. Ownership rights and limited real rights on land are registered on these parcels. The question can be raised if this "flat world" is satisfactory. After all, it cannot be denied that the dimensions of real rights on land are not only fixed in 2D, by the boundaries of the parcel. These rights have also a spatial component in the third dimension, in height and depth.
According to the Articles 20 and 21 of Book 5 of the *Dutch Civil Code* (*1992*) the rights of the owner of land reach from the middle of the earth up to the sky. Ownership of land comprises also the buildings and works forming a permanent part of the land. Horizontal division of ownerships rights is possible by establishing rights and limited rights on surface parcels, such as a right of superficies or apartment ownership (*Nieper and Ploeger*, 1999; *Stoter*, 2000). A right of superficies is a limited real right that entitles its holder to build and have a building (or an other type of construction) in, on or above the land owned by another. As a limited real right it restricts the landowner in his use: he has to tolerate the existence of the building. On the other hand, the holder of the right of superficies is the full owner of the erected building. For a description of the right of apartment we refer to our paper (*Stoter and Ploeger,* 2002*).*
The 3D component is not important as far as only one person (or group of persons) is entitled to the parcel. However, in particular cases, it is not so obvious that a cadastre is flat. These we call "complex situations". 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. For example: a building is divided in several apartments, and they belong to different owners. Or the owner of a railway line grants

someone the right to erect an office block 10 meters above the tracks. Other examples of multiple use of space are tunnels, pipelines, cables and underground extraction of minerals.

This paper describes the 3D aspects in the creation of a fundament for the design and development of a generic cadastral data model which could support the introduction of standards in the cadastral domain (*Oosterom and Lemmen*, 2002).
First two cases of 3D situations are described: a railway tunnel that crosses parcel boundaries and a building complex (section 2). The cases are part of the 3D cadastre research that is carried out at the Department of Geodesy in collaboration with the Netherlands' Kadaster (*Stoter and Ploeger*, 2002; *Stoter and Ploeger*, 2003). Based on the case studies, the 3D aspects that are relevant for cadastral data modeling are considered (section 3 and 4).

2. CASE STUDIES

In this section, we will describe two cases to show how complex situations are registered within the current cadastral registration system. The two cases are selected to show the characteristics of different 3D situations and their typical problems.
The first case focuses on cross boundary objects. The second is an illustration of a building complex and the use of rights in layers.

Case study 1: A drilled railway tunnel in rural area
In the Netherlands the Paris–Amsterdam High Speed Railway (planned to be finished in 2006) is currently under construction (Figure 1). Since this railway is passing through unaffected rural land, it was decided to drill a tunnel for this part of the railway.
The project team of the tunnel provided us with the 3D data of the tunnel, which we imported as one spatial object (a line-shaped object) into the cadastral DBMS. Therefore it was possible to query the legal status of the intersecting parcels.

The tunnel itself is about 8.5 kilometers long: 7.160 meters for the actual drilled tunnel and two entrance sections of 660 meters and 770 meters in length.

```
SQL> select sdo_geom.sdo_length(shape, 0.1) from hsl_railwaytunnel;

SDO_GEOM.SDO_LENGTH(SHAPE,0.1)
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                    8580420.07
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Note that in this case study we used a line for representing the tunnel, while the tunnel is 15 metres in width.

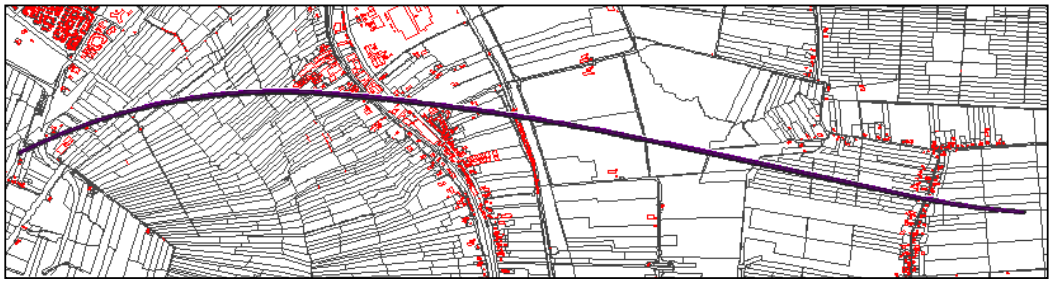


Figure 1: The railway tunnel in the "Green Heart" of the Netherlands.

In case cross-boundary 3D objects (objects that cross parcel boundaries), such as pipelines and tunnels, the 2D parcel is strongly limiting the amount of information that can be obtained. First of all this is due to the fact that the physical object is partitioned over the many parcels it intersects with. The rights that are referring to the 3D physical object are only registered by means of ownerships rights, limited rights, and restrictions that are established on the intersecting parcels. No information on the whole object is available, neither is spatial information available on the concerning rights.
In November 2001 the activities for the tunnel started. The realization of the tunnel is planned for 2004. We had access to two snapshots of the cadastral database: June 2000 and June 2001. In between most of rights needed by the Ministry of Transport and Public Works were obtained and registered. For this reason we were able to compare the different status of the rights on the parcels that intersect with the tunnel. The results of this investigation are shown in the table 1.
As can be concluded from this table, at the location of the planned tunnel many changes have taken place between June 2000 and June 2001. Of the original 104 parcels that intersect with the tunnel, 50 will stay intact. The other 54 will be subdivided because the tunnel will be built below just a part of these parcels. Most of those 54 parcels will be divided in two. A minority of them will be divided in three, or even four new parcels.
On the 104 intersecting parcels, in June 2000 the Ministry of Transport and Public Works had a right on 12 intersecting parcels (all ownership rights), while in June 2001, the Ministry had a right on 80 intersecting parcels (44 ownership rights and 36 rights of superficies). The intersecting parcels affected with those 80 rights are also affected with the legal notification 'OB' (underground construction), with the Ministry as subject. In the case of June 2000, none of the intersecting parcels had an 'OB' notification.
In June 2001, there are still 24 parcels left without a right held by the Ministry.

	June 2000	June 2001
1. How many parcels are intersecting with the projection of the tunnel	104	104
2. How many of the intersecting parcels are part parcels	0	54
3. How many parcels of (1) have a right that belongs to the Ministry of Transport and Public Works	12	80
4. How many parcels (including part parcels) have a right that belongs to the Ministry of Transport and Public Works	12	91
5. How many of the rights mentioned in (3) are right of ownership	12	44
6. How many of the rights mentioned in (3) are right of superficies	0	36
7. How many of the rights mentioned in (4) are right of ownership (registered both on part parcels and complete parcels)	12	53
8. How many of the rights mentioned in (4) are right of superficies (all registered on part parcels)	0	38
9. How many intersected (complete) parcels are affected with a legal notification	19	51
10. How many intersected parcels, including part parcels, are affected with a legal notification	19	67
11. How many of the notifications in (9) belong to the Ministry	0	34

of Transport and Public Works		
12. How many of the notifications in (10) belong to the Ministry of Transport and Public Works	0	36

Table 1: Results of the queries on the legal status of the parcels intersecting with the railway tunnel passing through the 'Green Heart' of the Netherlands.

Case 2: Building complex

"Den Haag Centraal" is a building complex in the city centre of The Hague. It is a combination of a multi-floor public transport interchange (bus/tram station and railway station), an office centre and shops (see figure 2). All parts of this complex are owned by different companies. This is achieved by dividing the high building (office and railway station) in apartments rights, and the establishment of a right of superficies for the bus/tram station on top of the railway platforms.

Figure 2: Den Haag Centraal. Combination of a business centre, a railway station and a bus/tram station.

The cadastral map of this complex is shown in figure 3. The bus/tram station on top of the railway platform is erected on parcel '13295', the business center is on top of the railway station on parcel '12131'.

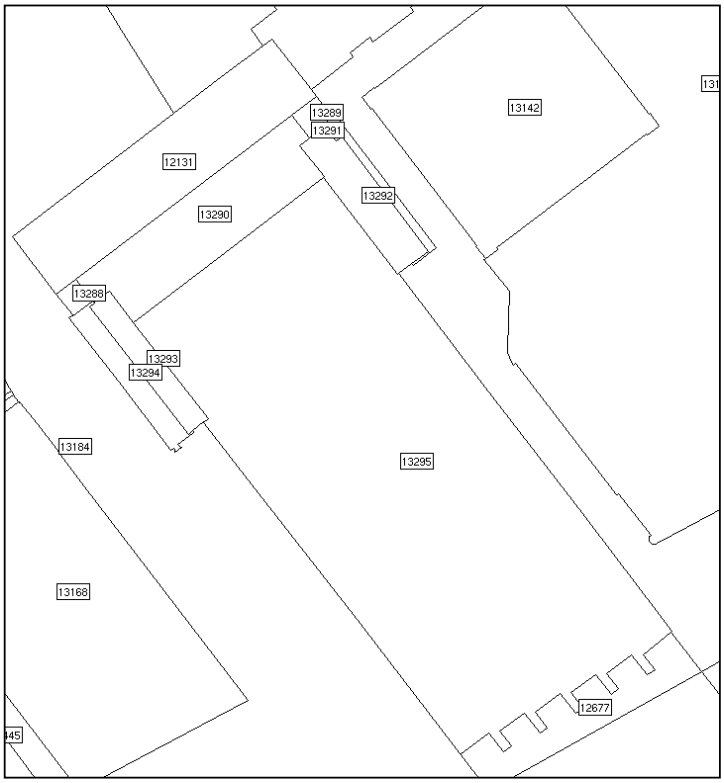


Figure 3: The cadastral map of 'Den Haag Centraal'.

According to the cadastral DBMS, the right of the concerning parcels are as follows:

PARCEL	KIND_OF_RIGHT	RIGHT_OWNER
12131	VE	VERENIGING VAN EIGENAREN STICHTHAGE TE 'S-GRAVENHAGE
	--(divided into two apartments: 12205A0001 and 12205A0002)	
12205A0002	VE	STICHTHAGE TRUST B.V. GEV. TE'S-GRAVENHAGE
12205A0001	VE	NS VASTGOED BV
13288	VE	NS VASTGOED BV
13289	VE	NS VASTGOED BV
13290	VE	NS VASTGOED BV
13291	EVOS	NS VASTGOED BV
13291	OS	Gemeente Den Haag
13292	EVOS	NS VASTGOED BV
13292	OS	Gemeente Den Haag
13293	EVOS	NS VASTGOED BV
13293	OS	Gemeente Den Haag
13294	EVOS	NS VASTGOED BV
13294	OS	Gemeente Den Haag
13295	EVOS	NS Railinfratrust BV
13295	OS	Gemeente Den Haag

VE = full right of ownership
OS = right of superficies
EVOS = right of ownership, restricted by a right of superficies

Analyzing these data, it is clear which persons have a right on the concerning parcels. So, for instance for the parcel 13295 it shows that "NS Railinfratrust BV" is owner of the land (with the railway platforms), and that the municipality of The Hague (in Dutch: gemeente Den Haag) is holder of the right of superficies (tram/bus station). However, neither these data nor the cadastral map give insight how on every single parcel the rights are divided in the vertical

dimension. Even there is no indication in the cadastre that the municipality is the full owner of the bus/tram station. A study in the Public Registers did not reveal much more information. Except for parcel 12131 (divided in apartment rights), the concerning deeds do not contain a spatial description or a (clear) drawing to clarify the division in ownerships rights on every parcel.

3. 3D ASPECTS OF CADASTRAL DATA MODELLING

To discuss how a 3D approach of a cadastre can improve the registration of 3D situations, we use the actual case of the HSL tunnel. We used the 3D information on the tunnel and the cadastral information to create fictive cadastral maps to illustrate the possibilities of registering 3D cross-boundary objects. Therefore, one should be aware of the fact that although the cadastral map of 2000 was used as a basis, the examples of maps in this section don't show the actual parcel boundaries: they are only meant to clarify the alternatives.
The section starts with a description of the current practise and than two alternatives are described to improve the registration of 3D situations: 1) the registration of rights in 3D and 2) the registration of the legal space of physical objects.

Current practise: registration in 2D

The first map (figure 4, left) would be the result if all parcels intersecting with the 3D object were completely affected with a right to build the tunnel in the underground. The location of the 3D object can (vaguely) be indicated when all parcels that are intersecting with the 3D object are selected.

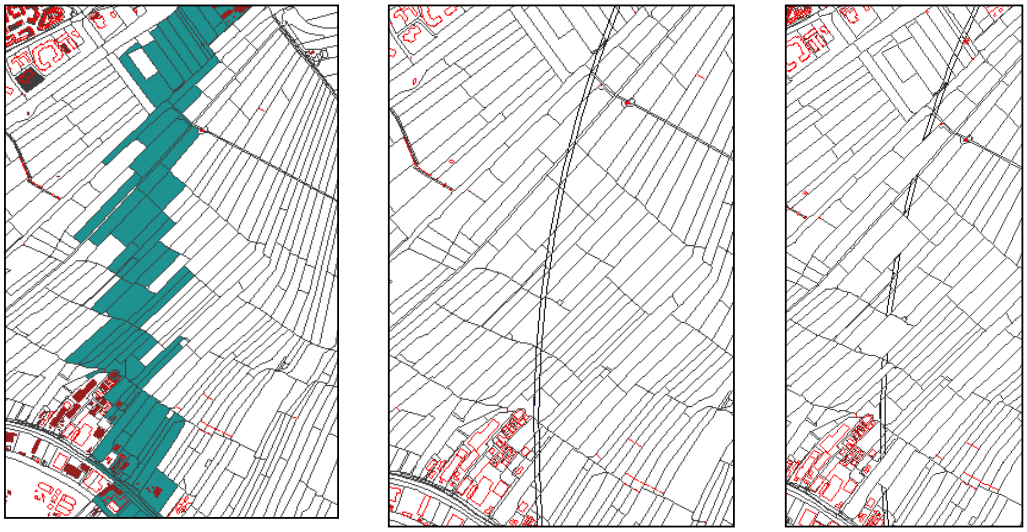


Figure 4: Left: whole parcel is affected, middle: new parcels are generated which results in a parcel pattern reflecting the 2D extent of the 3D object, right: combination of new parcels and parcels that are not divided.

This query is actually not possible in the current cadastral DBMS, since the 3D object itself (in this case the tunnel) is not maintained. Therefore, the relationships between the 3D object and the restrictions and notifications that are established are not stored. The only information that the cadastral system can provide is what rights, notifications and restrictions are established on a parcel and who are the subjects (natural and non-natural persons) of the rights, notifications and restrictions. In the case of the HSL tunnel, this subject is the Ministry of Transport and Public Works. Since the Ministry owns many other objects as well, this does not give insight in the nature of this 3D object: the object could be a viaduct, a road or a tunnel.
In addition, since the spatial extent of the objects is not maintained the following queries cannot be performed: which parcels intersect with the full 3D object; what rights, restrictions, or legal notifications are established on the parcels intersecting with the 3D object; are there any 3D objects (tunnels, pipelines) intersecting with a specific parcel etc.
When the tunnel intersects with a parcel only partially, normally the ownership or the right of superficies of only a part of the land will be obtained. This will lead to the creation of new parcels. Figure 4, middle illustrates this situation: the Ministry has obtained rights of ownership or superficies for the extent of the tunnel (with a needed safety zone on both sides). New parcels are generated. Still the relation between the complete 3D object (tunnel) and all the parcels is not maintained in the DBMS. Because of the pattern of (new) parcels, the location and direction of the tunnel is clearly visible. But it is important to realize this is not intended and the result of a limitation of the property rights in 2D within the boundaries of the existing parcels. In the case when also limited rights are established for constructions that have been built on top of the tunnel this image will be completely disturbed.
This is also the case in the figure 4, right. It is more realistic to suppose that the Ministry is not owner of only the land right above the tunnel, but also of complete parcels. For example when the Ministry already owned some parcels before the construction of the tunnel started, or when during the negotiations they agreed to buy all the land from the original owner, and not only the small zone that was actually needed. Is this the case, there is no need to generate new parcels and no rights or legal notifications referring to the tunnel are registered on these parcels.

Two alternatives

In conclusion, the current registration practise does not give sufficient insight in the 2D and 3D location of the tunnel or the vertical dimension (depth and height) of the rights established for the tunnel. Also the tunnel itself cannot be queried in the current cadastral registration system. To overcome these limitations, two alternatives have been introduced in our 3D cadastre research. These will be described in this section.

Registration of the 3D extend of rights

The current registration of 3D situations can be improved by means of a 3D right-object. This 3D right-object is the 3D representation of a right that is established on a parcel (Stoter and Ploeger, 2002). The 2D extent of a 3D right-object is the actual parcel-boundary. In this case we will use the new parcel boundaries as shown in figure 4, in the middle. The upper and lower limits of the 3D right-object are the upper and lower limits of the space where the right applies for (Stoter and Ploeger, 2002). The 3D right-object gives insight in the vertical dimension of the rights established. Now we can see that the rights are established for an underground construction and also the depth of the construction, which is a considerable improvement of current registration practise.
The UML class diagram (Warmer and Kleppe, 1998) of 3D right-objects is shown in figure 5. For every right that is established on a parcel and that concerns a complex situation (one

parcel is used by more than one persons) a 3D right-object is maintained. This contains the 3D representation of the right, which is also maintained in the DBMS. All 3D right-objects belonging to one physical object can be found since they refer to the same 3D physical object.

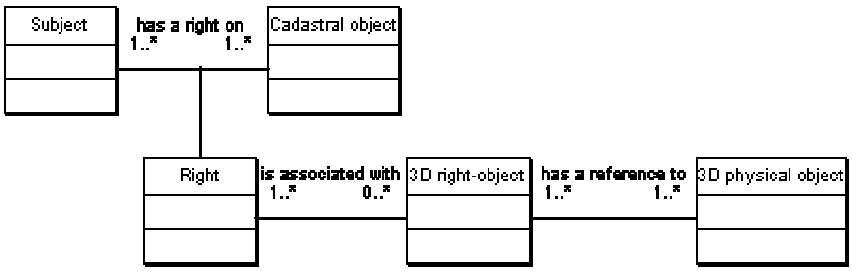


Figure 5: UML class diagram of 3D right-objects

This data model needs some adjustment compared to the current cadastral model (figure 6), but the principle of the 2D parcels as objects remains the same.

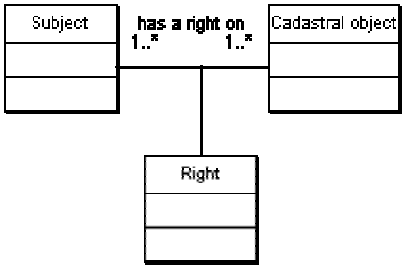
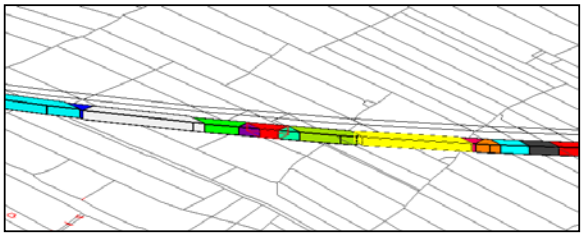
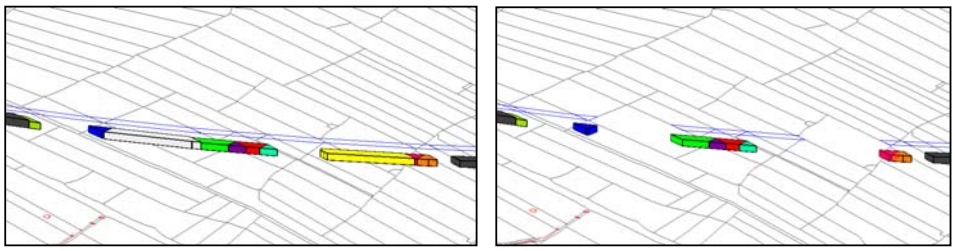


Figure 6: UML class diagram of the current cadastre

As was discussed in the 2D traditional registration, the registration of a right for the tunnel will not take place, when the Ministry owns the intersecting parcel. This leads to 'gaps' in the 3D registration. This is clearly illustrated in figures 7b and 7c. Figure 7b shows the situation when new parcels are created and some of these parcels are in full ownership with the Ministry of Transport and Public Works. For those parcels a 3D right-object will not be created (the Ministry owns the whole parcel column). The situation is even less clear in figure 7c. This will be the case when both new parcels and original parcels that are not divided are in full ownership.



(a)



(b) (c)

Figure 7: 3D right-objects representing the 3D extent of rights established on 2D parcels for the HSL tunnel owned by the Ministry. Figure 7a: all the parcels are encumbered by right of superficies, new parcels are created for all intersecting parcels. Figure 7b: as figure 7a, but now three newly created parcels are in full ownership. Figure 7c: three newly created parcels are in full ownership, two parcels that are not subdivided are in full ownership. All the other (new) parcels are encumbered by a right of superfices.

Legal space of object is registered

How to know the actual location of the tunnel and to avoid the 'gaps' in the registration? The only solution is the registration of the complete construction itself (figure 8). The most optimal solution would be to register the 3D physical object itself together with a spatial description of the legal space of the object (*Stoter and Ploeger,* 2002). The legal space is the space that is relevant for the cadastre (bounding envelope of the object), which is usually larger than the physical extent of the object itself (for example including a safety zone).

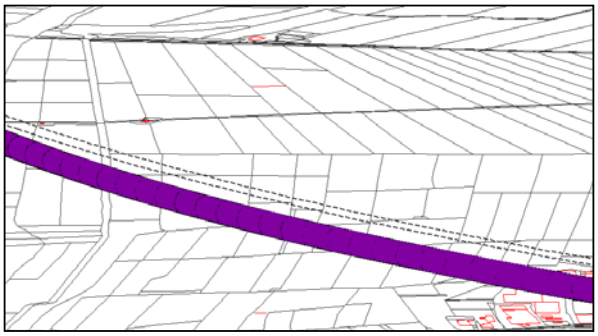


Figure 8: Registration of the legal space of the HSL tunnel. The dashed line is the projection of the tunnel on the surface. Note that the parcels are not divided into smaller parcels.

The UML class diagram of this registration is shown in figure 9. Apart from parcels (cadastral objects), 3D physical objects are also registered. The holder of the 3D physical object is a subject with a right on a 3D physical object (factual ownership, which is not the same as the juridical ownership), by means of (limited) rights on the intersecting parcels. 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 were the owner. Rights and limited rights are still registered on parcels. The only right that a person can get on a 3D physical object is that he

can become the holder of this object. Therefore, a 3D physical object is not a subset of a cadastral object: 3D physical objects are maintained in addition to 2D parcels

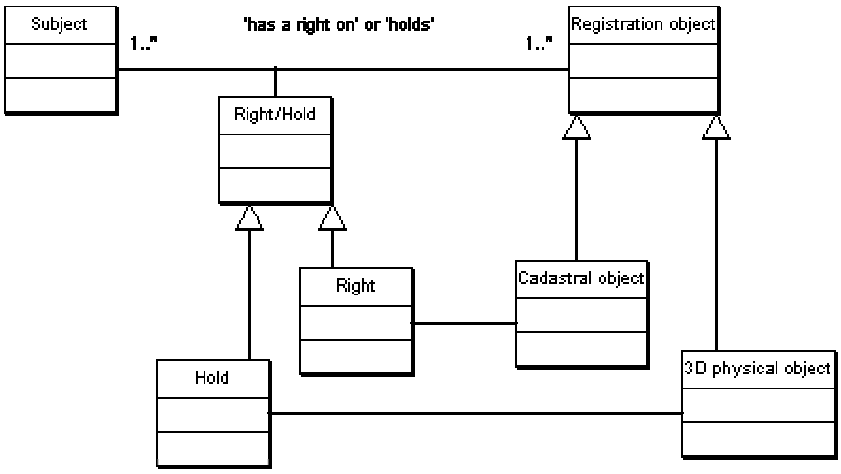


Figure 9: UML class diagram of 3D physical objects

The relationship between the legal space of the 3D object and the intersecting parcels is stored implicitly, because the holder of a 3D object is maintained. This is the same (non-natural) person who has a right on the intersecting parcels.
The solution of registering the legal space of 3D objects compensates all the complications that were met earlier. The intersecting parcels still need a kind of legal notification referring to the tunnel, but the parcels need not to be divided into smaller parcels. The spatial relationships between parcels and the (legal space of the) 3D object can be maintained with spatial functions in the DBMS.
The result is a full 3D cadastre (*Stoter et al.,* 2002). An important disadvantage of this solution is that it requires considerable adjustments in the cadastre (*Stoter and Ploeger,* 2002), therefore for the mid-term future it is better to focus on a more feasible solution to improve insight in 3D.

4. PROTOTYPE APPLIED TO CASE "DEN HAAG CENTRAAL"

The 3D right-objects offer the best possibilities for the mid-term future. To underline the potentials of this concept, we apply the concept to the case of "Den Haag Centraal".
For the building complex "Den Haag Centraal" the 3D right-table looks as follows:

```
PARCEL   Z_LIST
------   --------------
12131     Z_ARRAY(0, 12, 40)
13290     Z_ARRAY(0, 12)
13288     Z_ARRAY(0, 12)
13289     Z_ARRAY(0, 12)
13294     Z_ARRAY(0, 3, 12)
13291     Z_ARRAY(0, 3, 12)
13293     Z_ARRAY(0, 3, 12)
13292     Z_ARRAY(0, 3, 12)
13295     Z_ARRAY(0, 6, 12)
```

For every parcel a z-list is stored, that defines the upper and lower limits of rights established on the parcel. For example, the vertical extents of the rights on the parcel that contains the tram and bus station and the railway platform (parcel '13295'), are as follows:

- railway platform (owned by "NS Vastgoed"): 0 to 6 m
- tram/bus station (right of superficies, holder Municipality of Den Haag): 6m to 12 m.

While in this case the notarial deed gives no information about the boundaries of the established right of superficies in the third dimension, the levels were obtained by measuring the building ourselves.

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. 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 the visualization of the 3D right-objects is different than the actual built construction (e.g. when a right of superficies exceeds the actual construction).

The visualization of the generated 3D right-objects is shown in figure 10.

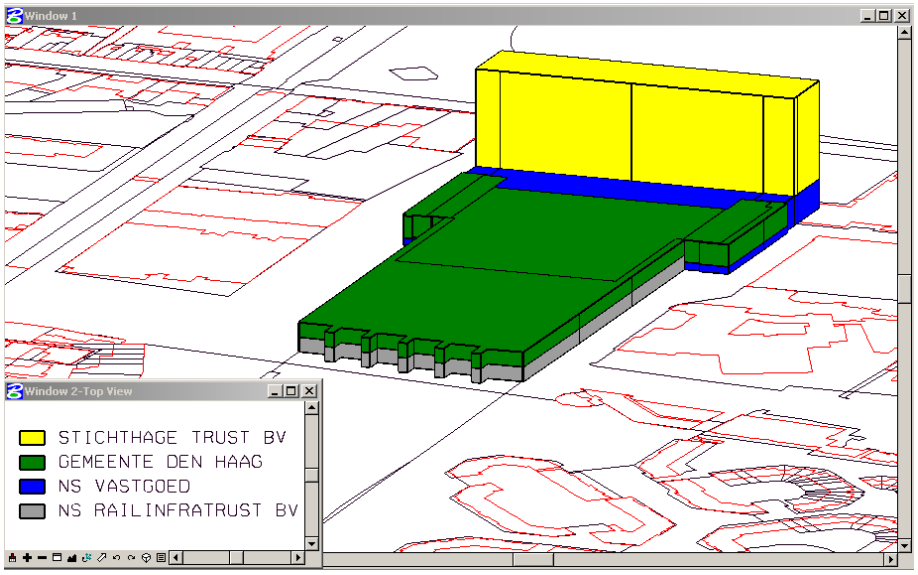


Figure 10: Visualization of 3D right-objects that were generated in the DBMS ("Den Haag Centraal").

This visualization gives a clear insight of the various rights in the building complex. Not only it gives an indication of the spatial component of the property rights on each of the concerned parcels, it also shows the relation between the rights established on adjacent parcels. The 3D map of Den Haag Centraal clearly shows that the Municipality of Den Haag is not only holding the right of superficies on parcel 13295 (the big parcel in the center, with the railway platforms on ground level), but also of the parcels 13291, 13292, 13293 and 13294. At a glance one can see that the Municipality is owner of the bus/tram station on the second floor,

with the adjacent entrances at left and right hand side of the railway station. This is a great advantage compared to the traditional 2D cadastral map.
However it must be noticed that the 3D map only shows the 3D right-objects and not the physical object (in this case the whole complex) itself. The physical object is only used to determine and visualize the vertical limits of the right of the landowner and the limited real rights. Also it is important to notice that it is possible that a part of the structure is not visualized because it is in full ownership with the owner of the land. In the previous section we illustrated this by the example of a railway tunnel. In figure 7 this is the case with parcel 12677: the small parcel just in front of the railway platforms and bus station. In fact the railway platforms are also erected on this parcel. However this part of the complex is not visualized because "NS Railinfratrust BV" holds it in full ownership. Generally speaking, every part of a complex that is erected on a parcel that is in full ownership will not be shown on the 3D map.

5. CONCLUSION

Cross-boundary 3D objects are registered by means of rights, restrictions and notifications on intersecting parcels. This leads to a fragmented pattern of parcels. Also information on the 3D objects itself (with a 2D or 3D description) is not available since the object itself is not registered in the cadastral DBMS. The 3D object is divided into parts that match with the surface parcel. In the current registration one can only see which persons have a right on the intersecting parcels, but the 3D extent of those rights is not registered. 'Gaps' may occur since some parcels are already fully owned by the holder of the 3D object.
These 3D aspects should be taken into consideration in the process of developing a general cadastral data model.
To overcome the limitations, the best solution would be to register the legal space of 3D physical objects or apartment units. However, this requires considerable adjustment of the current cadastre.
For the mid-term future storing the 3D representation of rights established on 2D parcels (right of superficies and apartment rights) improves insight in the spatial extent of rights. 3D right-objects give insight in the third dimension of rights established for a 3D object, while little adjustment of the current registration is required. The main change is that upper and lower limits of rights have to be registered.
The insight in the rights in 3D is a considerable improvement compared to the current possibilities of the cadastral registration system, although it does not give a clear representation of the situation in all cases, as was shown in this paper. Therefore, the focus for the long-term future should be on the registration of the legal space of 3D physical objects.

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