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Property in 3D—registration of multiple use of space: current practice in Holland and the need for a 3D cadastre

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Abstract

A cadastral registration system provides insight in rights and limited rights related to (2D) parcels. In case of multiple use of space, the 2D parcel has shown its limitations. To illustrate this we describe two cases in this article. At our Department a research is carried out in collaboration with the Netherlands' Kadaster to study the 3D issue of cadastral registration in a fundamental way. During this research a prototype of a 3D cadastre was developed, in which rights established on 2D parcels can be represented in 3D (3D right-objects). We will give a description of this prototype and will demonstrate that the introduction of 3D right-objects improves the insight in the vertical component of rights considerably by applying this concept to the described cases. Future research will focus on the registration of 3D physical objects (objects as they occur in the real world). The last will require more drastic adjustments in the current cadastral registration system.

Keywords: 3D cadastre; Multiple use of space; Geo-DBMS

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 also have a spatial component in the third dimension, in height and depth. In most countries the right of ownership reaches from the middle of the earth up to the sky, according to the Latin maxim: 'cujus est solum ejus est usque ad coelum et ad inferos'.

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So why is the cadastre flat? The answer must be that in far most cases the representation of a 3D legal reality in a flat 2D cadastre is sufficient. There is no need to add the third dimension to this kind of geo-information. The spatial component is not important as long 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 should be 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 m above the tracks. Other examples of multiple use of space are tunnels, pipelines, cables and underground extraction of minerals. Can a 2D cadastre really cope with these situations?

In 2000 the Department of Geodesy of Delft University of Technology started a research to study the needs and possibilities of the registration of multiple use of space in a 3D cadastre. This research is carried out in collaboration with the Netherlands' Kadaster. As part of this research we investigated five cases from practice, of which we will present the last two in this article:

- a building on top of a road (Stoter & Salzmann, 2001);
- railway tunnel under the Green Heart of the Netherlands (Stoter & Zlatanova, 2002);
- two pipelines for gas transport;
- "Den Haag Centraal": a building complex in the city centre of The Hague;
- a small apartment complex.

We will start with a short overview of the current registration practice in the Netherlands. This background knowledge is needed to understand the two cases. For each of these cases we examine first the actual registration of the property rights. How is the Netherlands' Kadaster dealing with multiple use of space at the moment? Next we discuss the need of a registration in 3D. What problems rise with the representation of the legal situation in 2D in each of the cases?

During the research a concept of a 3D cadastre has been developed, as well as prototype implementations. We will give a description of both the prototype and the implementations and we will apply the prototype implementations to the cases. In our conclusion we will examine if the developed concept and the proposed implementations offer improvements for the problems mentioned.

2. Current registration practice in the Netherlands

2.1. Registration of ownership in complex situations

According to the Articles 20 and 21 of Book 5 of the Dutch Civil Code (1992) the right of ownership of land reaches from the middle of the earth up to the sky. Also

ownership of land comprises 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 & Ploeger, 1999; Stoter, 2000).

In cases of multiple use of space the Netherlands' Kadaster registers the ownership and limited rights just on the flat, 2D parcels. As we will demonstrate, this kind of registration has limitations to give a clear representation of the 3D component of the concerning rights.

2.2. Registration by the Netherlands' Kadaster

The Netherlands' Kadaster bears the responsibility for the cadastral registration in the Netherlands: the registration of the parcel boundaries and the registration of the legal status of the parcels. This system consists of (Lemmen, Oosterbroek, & van Oosterom, 1998):

- a 2D geo-DBMS for maintaining the geometry and topology of parcels (and *buildings for reference purposes) called LKI (Landmeetkundig* Kartografisch Informatiesysteem, 'Information system for Surveying and Mapping') and
- an administrative DBMS for legal and other administrative data related to parcels called AKR (*Automatisering Kadastrale Registratie*, 'Automated Cadastral Registration').

The Kadaster also maintains the Public Registers (Openbare registers): a registration of notarial deeds creating or transferring real rights to land. These deeds are (analogously) registered and archived in chronological order. The cadastral registration system makes the information in the deeds referring to individual parcels accessible.

3. Cases

We will now describe two cases to show how complex situations are registered within the current cadastral registration system.

3.1. Case 1: Den Haag Centraal

"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 Fig. 1). 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.

We will discuss apartment rights in more detail in the second case. Here we take a closer look at the right of superficies (*opstalrecht*). 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: 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. The right of superficies causes a horizontal division in ownership of real estate.

The cadastral map of this complex is shown in Fig. 2. On parcel '13295' we find the railway platforms and the bus/tram station on top of it. The business center is situated above the railway station on parcel '12131'.

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.
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). The holder of the right of superficies is entitled to build the tram and bus station above the railway platforms.

However, neither this data nor the cadastral map gives insight in how on every single parcel the rights are divided in the vertical dimension. There is even no indication in the cadastral registration system that the municipality is the full owner of the bus/tram station. A study in the Public Registers did not reveal much more

Fig. 1. Den Haag Centraal. Combination of a business centre, a railway station and a bus/tram station.

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 of ownerships rights on every parcel.

3.2. Case 2: apartment complex

A typical form of multiple use of space, known in Dutch law since 1953, is apartment ownership (condominium ownership).

For this case, we used a 'simple' apartment complex, consisting of one ground parcel and three apartments. One apartment is located on the ground floor, and the two other apartments are located on the second and third floor, next to each other, with an entrance on groundlevel (see Fig. 3).

In Germany, France and most other European countries the legislation on apartment ownership is based on the so-called ''dual system'' (Van Velten & Aldridge, 1996). Every apartment owner has the full ownership of a part of the building (apartment). The communal areas of the building, such as staircases and elevators are held in co-ownership. This can be described as compulsory co-ownership, or an accessory restricted co-ownership. ''Accessory'' because it cannot be separated from the ownership of the apartment, ''restricted'' because while the building is divided into apartments, the separation and division of the common areas is not possible.

Three European countries have adopted the ''unitary system'': Austria, Switzerland and the Netherlands (Van Velten & Aldridge, 1996). It is important to notice

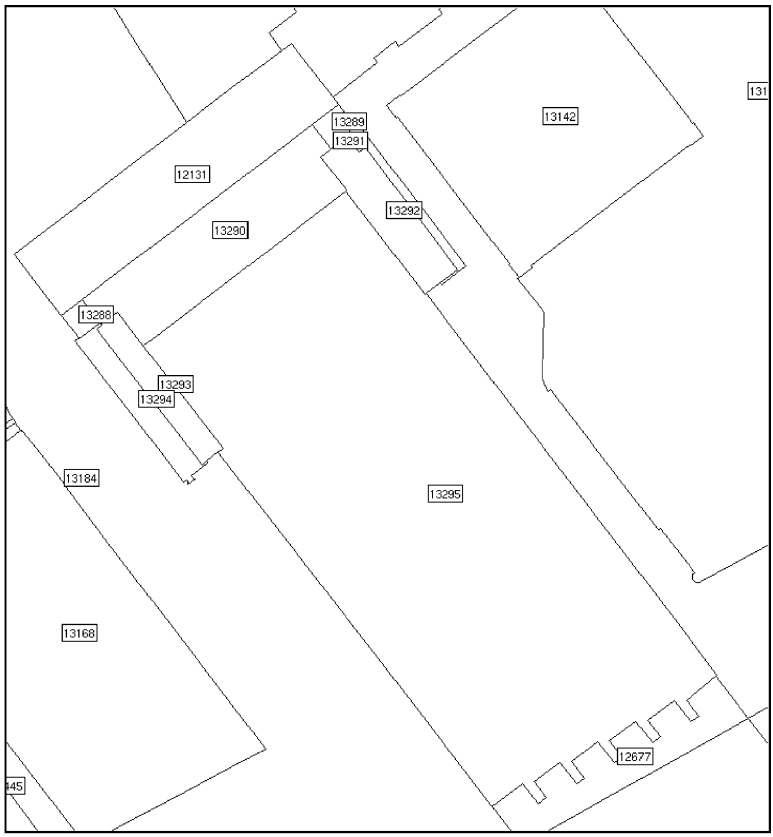

Fig. 2. The cadastral map of 'Den Haag Centraal'.

Fig. 3. Example of an apartment complex (left) and an overview of the whole street (right).

that in this system the apartment ownership is based on co-ownership of the whole complex. As we shall see, this is reflected in the way apartment ownership is registered in the Netherlands' Kadaster.

Article 106 of Book 5 of the Dutch Civil Code (1992) describes apartment ownership (or apartment right (*apartementsrecht*) as follows:

3. An apartment right means a share in the property involved in the division which comprises the right to exclusive use of certain parts of the building which, as indicated by their lay-out, are intended to be used as separate units. The share can also include the right to exclusive use of certain parts of the land pertaining to the building.
4. An apartment owner means a person entitled to an apartment right.

So the owners are joint owners of the entire building and the underlying ground. This co-ownership includes the right to have the exclusive use of a certain part of the building, the apartment.

The division in apartment rights is based on a notarial deed, the so-called "deed of division" (*splitsingsakte*). A (scanned or analogue) plan is obliged in this deed. This plan gives an overview of the building and a detailed plan of each floor. Thick dark lines indicate the borders of every apartment, that is the area of exclusive use. The individual apartments are numbered (see Fig. 4).

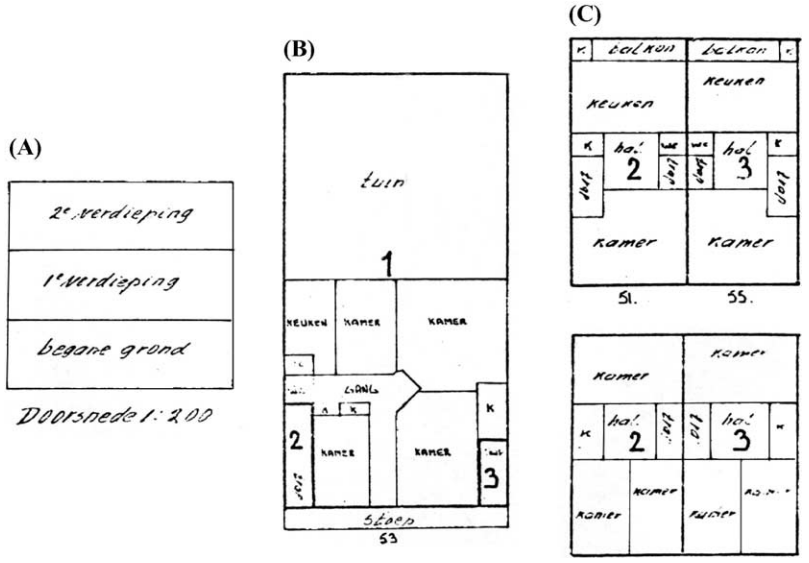

Fig. 4. Drawing belonging to the deed of division of the apartment complex in Fig. 3, with A: cross-section, B: first floor, C upper: second floor and C lower: third floor. The individual apartments are indicated by '1', '2' and '3'.

The rights on the parcel and the apartments according to the cadastral registration system are as follows:

PARCEL	KIND_OF_RIGHT	RIGHT_OWNER
5238 G0	VE	VERENIGING VAN EIGENAREN HOORNBEEKSTRAAT 51,55, DELFT
6408 A3	VE	BALLERING
6408 A2	VE	JANSSEN
6408 A1	VE	STOTER

VE = full right of ownership

At a first glance it seems that there are four owners, the *vereniging van eigenaren* (association of owners) and the holders of each of the three apartments. But this conclusion is not correct. The parcel 5238 G0 refers to the ground parcel. This parcel, with the apartment complex erected on it, is co-owned by all the holders of apartments rights. In practise the Kadaster names the *vereniging van eigenaren* (the association of owners) as owner. From a legal point of view this is not correct. The complex is co-owned by all the apartment owners, not by the association. In Dutch law this association of co-owners is merely a legal body entrusted with the day-to-day administration and management of the complex. All the co-owners of the complex are compulsory members of this association.

Apart from the (co-owned) ground parcel, we find the individual apartments, each indicated by a unique number (6408 A1, 6408 A2, 6408 A3). The suffix A shows this number refers to an apartment right. The last digit is the same as the apartment number in the deed of division.

It is most important to realize that the individual apartments, the areas of exclusive use, cannot be found on the cadastral map (see Fig. 5). The Public Registers have to be queried to find the plan of division. Another disadvantage of this way of registration is that the plans in the notarial deed are drawn in a local coordinate system (in 2D layers). When coordinates were defined in the national reference system they could be combined with the cadastral map or other geodata (e.g. topographic data). However, the addition of 3D information on the individual apartments in the cadastral system itself would especially enhance insight.

4. Need for a 3D cadastral registration

These two cases illustrate the main problem that arises with 3D situations in urban areas in the current cadastral registration. It is clear which persons have a right on a parcel. However the way these rights are located on top of each other is not registered: spatial information on rights in the vertical dimension is unavailable. The Public Registers need to be consulted to get insight in the actual 3D situation in

Fig. 5. The cadastral map of the apartment complex in Fig. 3. The parcel concerned is indicated. The front of the building is indicated with an arrow. Note that the parcel is larger than the footprint of the building.

the case of apartment rights. For other cases (e.g. horizontal division of ownership by establishing a right of superficies) adding plans to deeds is voluntary, so consulting the Public Registers does not necessarily yield significantly more information.

5. Description of prototype of a 3D cadastre

Before we came to a feasible approach for a 3D cadastre for the medium-term feature we started with the concepts of three possible alternative solutions (Stoter, Salzmann, van Oosterom, & van der Molen, 2002):

- full 3D cadastre, in which 3D parcels and hence 3D rights are supported;
- hybrid solution, which means preservation of the 2D cadastral registration system and the registration of the situation in 3D within the 2D cadastral registration when this is required from a legal point of view; and
- 2D classical registration with references, which means preservation of the 2D cadastre with external references to representations of 3D situations (which is current practice).

In Stoter et al. (2002) we concluded that a hybrid approach for a 3D cadastre offers the best possibilities to meet the complications sketched above, both from a legal and technical point of view.

The hybrid approach consists of a registration of the 3D situation in addition to the existing 2D parcel registration. This concept of a 3D cadastre is translated into prototype implementations in the geo-DBMS. For the implementation we use Oracle

Spatial 9i. The prototype has been implemented in two ways: using spatial data types and using a topological model. For technical details of the implementation see (Stoter & van Oosterom, 2002).

For the registration of 2D parcels and 3D situations in one system, we start with a relatively simple solution: an extension of the current cadastral registration system, which comprise the registration of rights concerning 3D situations in 3D. This implementation is seen as a tool to get insight in the 3D aspect of rights ('visualization of rights in 3D'): it is not an exact representation on which conclusions with juridical consequences can be drawn.

5.1. The registration of 3D right-objects

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 and limited in the third dimension. 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 of the right. When more detail is required, e.g. in case only a part of a parcel deals with a complex situation, a new (2D) parcel boundary needs to be generated.

The 3D right-objects that are maintained are associated with a registered right and contain a reference to the whole spatial object (physical objects). Spatial and non-spatial characteristics of these physical objects might also be maintained in 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 consists of several rights belonging to this particular 3D physical object (right of superficies, condominium right etc). In this way a physical object, e.g. a tunnel is subdivided into parts according to the ground parcels.

It can be queried which parcels contain a right or limited right related to a specific 3D physical object. To identify this, a record with at least the identification (the *id*) of this 3D physical object has to be present within the system. This query cannot be performed in the current cadastral system, as there are no physical objects available. Neither can the 3D extent of a right be queried at the moment (to what height or depth extends the right of superficies?), while this is possible in the case of 3D right-objects.

A 3D right-object associated with a right on a parcel is only registered, when this is juridically required. That is in the case a limited real right is established. In other cases it is voluntary. For that reason it is possible that the 3D physical object is not completely known in the cadastral registration system. This can be illustrated by the example of a railway tunnel. This tunnel is built in the underground of six parcels. The owner of the tunnel (the company "T") is also the owner of two of these parcels. The other four parcels are owned by respectively A, B, C and D. For each of these parcels a right of superficies is established. In this case the 3D physical object is registered for four surface parcels and not necessarily for the two parcels owned by T. Therefore the uniformity of the registrations of 3D physical objects and with this insight in the 3D situation can be at risk.

5.2. The registration of 3D physical objects

A more advanced solution would also include the registering of 3D physical objects apart from (in addition to) 2D parcels. However, this solution requires considerable adjustments of the current cadastral registration system, technically as well as juridically. A registration of 3D physical objects needs to be organised and maintained and this registration could become a cadastral task. For the implementation of this registration a finite list of objects that need to be registered has to be made. It has to be decided whether this list can include 'empty space' objects or not. For this it is interesting to look at similar international experiences: 'air space parcels' are known in British Columbia (Gerremo & Hansson, 1998) while 'construction properties' in Norway (Onsrud, 2001) and '3D property units' in Sweden (Julstad & Ericsson, 2001) have to consist of actually built constructions. The last two will get legal force in the coming years. When 3D physical objects (as they are defined on the finite list) are realised, they have to be registered. To make the registration indisputable, a law will be needed to make the registration compulsory. From a technical point of view 3D physical objects are more difficult to maintain since the geometry of physical objects is more complex than the geometry of 3D right-objects (generating data, implementing data structures and spatial analyses are more complex).

When 3D physical objects are maintained, a 3D physical object can be queried (spatially and administratively) as a whole, e.g. which parcels are intersecting with (the projection of) a 3D physical object; which rights are established on these parcels; who are the right-owners? Furthermore gaps in the registration can be traced.

5.3. Prototype implementation

The aim of this research is a feasible solution in the medium-term future. Therefore we will focus first on the registration of rights in 3D (3D right-objects). Fig. 6 depicts the needed extension of the current cadastral data model in UML (Warmer & Kleppe, 1998).

To describe the rights concerning complex situations in 3D we will introduce a table (3D right-table) that contains for every parcel the different height-levels of ownership (z-list). The z-list contains n z-values corresponding to $n-1$ consecutive ranges associated with the parcel. 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 geometry of parcel boundaries. The 3D right-objects are identified by unique numbers that are based on the parcel number concerned.

Holders of a 3D right-object can be obtained by the right to which the 3D right-object is associated (e.g. a right of superficies). The right-owner of this right (subject) is the holder of the 3D right-object.

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. We have considered defining the lower and upper limits in more detail, however the Netherlands' Kadaster opted for this global solution: indicating one z-value for every

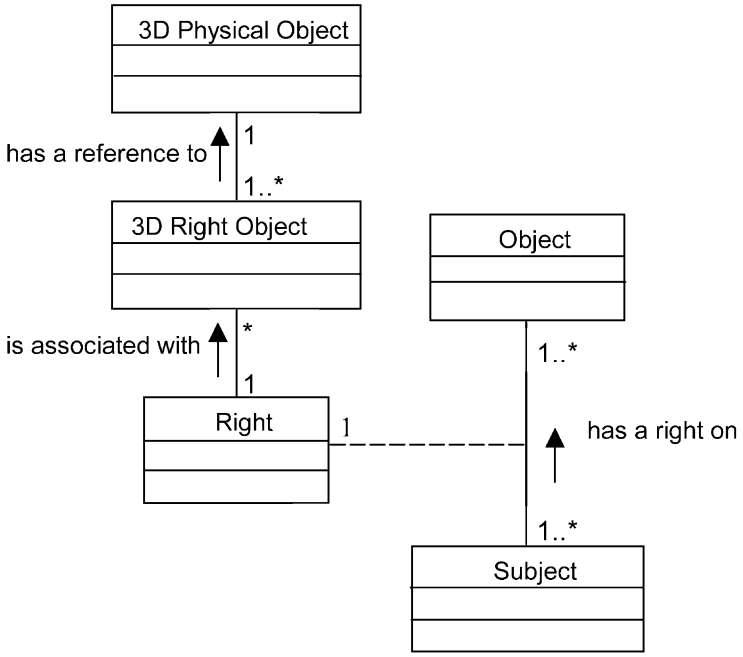

Fig. 6. UML class diagram for the cadastral data model including the registration of 3D right-objects: an object is a parcel or a condominium right and a subject is a person who has a right on an object.

horizontal boundary. More detail registered at the Kadaster makes the Kadaster responsible for the consequences of this information. Therefore we will elaborate on this solution. A future solution may define a 3D right-object in more detail.

5.4. Why CAD models do not comply a 3D cadastre

3D data is needed to represent 3D objects in the 3D cadastre. Since 3D data is available with designers, mostly as CAD models, it is a relevant question how this information can be used.

Municipalities, the Ministry of Transport and Public Works, and designers were visited in the search for usable CAD models. Based on this research the conclusion can be drawn that CAD models suitable for the 3D cadastre cannot or hardly be found. The first reason for this is that newly planned objects are mostly still designed in 2D by using linear profiles and cross-sections. 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 3D cadastre (as this is the most original source). In this process attention has to be paid to the conversion of local coordinates of the CAD files to absolute coordinates in the national coordinate frame.

In the design and building process, 3D CAD models are generated from the designs for visualisation purposes. Also those models cannot directly be used for the 3D cadastre.

Since CAD models contain much more details than is needed in the 3D cadastre it has to be studied what selections and generalisations are needed to obtain the relevant information such as the outer boundary of objects. When the Cadastre would register the detailed information that is available in CAD models, it would make the Cadastre responsible for this information, which they obviously want to avoid.

Furthermore, 3D CAD files can get unworkable large, since mostly they are not made for interactive purposes but to generate movies out of them. Furthermore the relevant objects can hardly be recognised in the file-based models and finally 3D spatial data in CAD files contain complex geometries and are sometimes parametrically described. At the moment these data cannot automatically be converted to the primitives that are available in the spatial DBMS, which is used for the 3D cadastre (point, lines, polygons, polyhedrons). Also once the 3D CAD objects will be available as geometries 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 have shown that it is a complex process to obtain the needed information (property boundaries in 3D) out of these models. For simple buildings it might still be straightforward, but for more complex situations (e.g. tunnels) it requires study on basic fundamentals in GIS science (generalization; converting parametrically described geometry to geometry primitives).

6. Prototype applied to cases

6.1. Case "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 concerning a 3D situation 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 Railinfratrust BV"): 0–6 m
- tram/bus station (right of superficies, holder Municipality of Den Haag): 6–12 m.

Because 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 Fig. 7.

This visualization gives a clear insight of the various rights in the building complex. Not only does it an indication of the spatial component of the property rights on each of the parcels, it also shows the relation between the rights established on adjacent parcels. This 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 on the

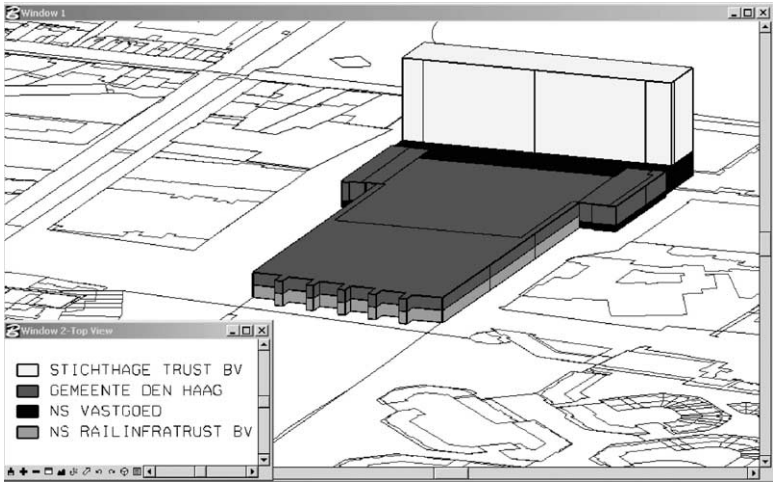

Fig. 7. Visualization of 3D right-objects that were generated in the DBMS ("Den Haag Centraal").

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 the left and right hand side of the railway station. This is a great advantage compared with 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. In the previous section we illustrated this by the example of a railway tunnel. In Fig. 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.

6.2. Apartment building

The case of the apartment building is more complicated, since on the first floor we find three apartment owners and on the second and third floor two owners, all established on one parcel. Furthermore, not the whole parcel is covered with the building. This is quite common for apartment complexes.

To be able to apply the z-list introduced earlier, the 2D boundaries of the properties (individual apartments) are generated, which gives the 2D objects as shown in Fig. 8, with object a (whole building minus b and c), b and c defined for the first floor and object d and e (both half of the building) defined for the second and third floor.

The 3D right-table for the whole apartment complex looks as follows:

PARCEL	Z_LIST
6408_a	Z_ARRAY(0,3)
6408_b	Z_ARRAY(0,3)
6408_c	Z_ARRAY(0,3)
6408_d	Z_ARRAY(3, 6, 10)
6408_e	Z_ARRAY(3, 6, 10)

Note that these are not parcel numbers but objects generated to define the inner boundaries of the apartments in order to extract them in 3D. This case shows two complications. First not only a horizontal division is needed to define the 3D right-objects but also a vertical division (dividing the parcel in smaller parts). This is obviously required when defining these 3D right-objects but the generation of the smaller parts is a big change in the concept if they get a legal status. Second there is overlap in the 3D right-objects when projecting them on the surface, which means

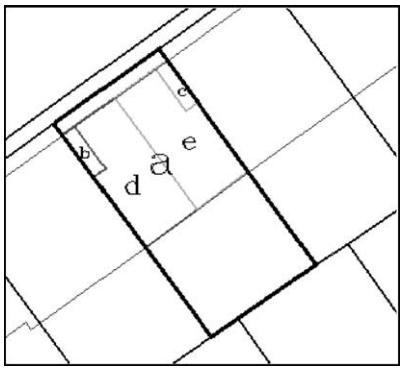

Fig. 8. The generated 2D objects: footprints of individual apartments on every floor.

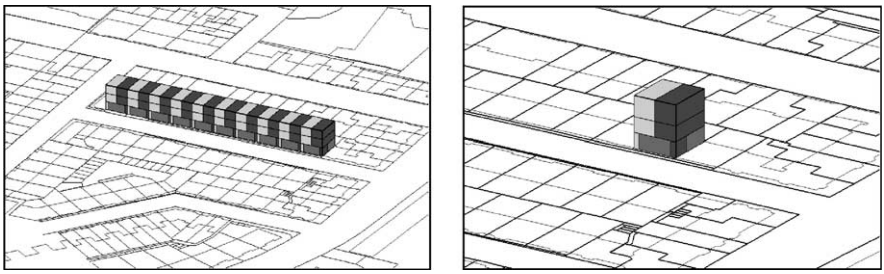

Fig. 9. Visualization of 3D right-objects (apartment rights) that were generated in the DBMS (left—all apartments in the street; right—the apartment complex of the case study which is the second complex from right).

that there is not a 2D parcel defining the 2D boundaries of the 3D right-objects. These two drawbacks could be solved when a full 3D approach would be used.

The visualization of the generated 3D right-objects is shown in Fig. 9.

7. Conclusion

The objective of every cadastral registration system is to give insight in rights on land. We analyzed two cases of multiple use of space: a building complex and a small apartment complex. We found that the use of 2D parcels as the only basis for registration has important limitations. The main problem is that the cadastral registration system cannot reflect the vertical component of ownership rights and real limited rights concerning complex situations.

To find a solution to this problem, we introduced 3D right-objects. These 3D representations of rights improve insight in spatially complex situation considerably, as was illustrated by applying this solution to the described cases. The 3D right-object starts with the 2D parcel boundary on which the right is established. This is extended into 3D by means of defining upper and lower limits of the right. This

approach yielded some complications in case of the apartment complex, which have to be studied further.

In conclusion, inserting 3D right-objects on the cadastral map gives an overview of the horizontal division of ownership, which is a significant enhancement of the current system. Incorporation of 3D right-objects in the cadastral registration system provides information on the vertical component of rights without having to consult the Public Registers. Furthermore, since references are maintained to the whole spatial object, all parcels can be found that are intersecting with one particular physical object (e.g. a tunnel). On the other hand, a drawback of the proposed prototype is that such objects above or below several 2D parcels have to be subdivided in as many 3D right-objects as there are parcels on the surface.

Based on the experiences in the case studies, the concept of a 3D cadastre as well as the prototype implementations will be improved to come to an optimal solution. Future research will also focus on the study if the approach of 3D right-objects suffices or a more advanced solution is required: the registration of 3D physical objects (as they occur in reality). This will require more drastic changes in the current cadastral registration system, both technically and legally.

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