Conceptual 3D Cadastral Model Applied in Several Countries

Jantien E. STOTER, Peter J. M. van OOSTEROM, Hendrik D. PLOEGER and Henri J. G. L. AALDERS, The Netherlands

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SUMMARY

The individualisation of property started initially with a division of land using 2D boundaries. This is why the central paradigm in cadastral registration is traditionally a 2D parcel. This paradigm needs to be adjusted since there is an increasing interest in using space above and below the surface. Today's cadastral registration should therefore be able to reflect the true principle of property rights: property rights always have entitled persons to volumes and not to just an area, otherwise the use of the land would have been impossible.
In our 3D cadastre research we described several conceptual models to improve cadastral registration. The most challenging conceptual model, the full 3D cadastre, is described in this paper. To prove the potentials of this model we studied several countries and states in which it is already possible to establish 3D property units with separate ownership from the legal point of view (Norway, Sweden, Queensland and British Colombia). As will be seen in this paper, the basic drawback of those solutions is that a complete 3D cadastral registration for these 3D property units is not available. We applied our full 3D cadastre model in a prototype to a case study in Queensland. The experiments of this case study showed that both the legal, organisational and technical aspects of a 3D cadastre have been solved, although it should be noted that there are non-trivial aspects (in the conversion and use of a 3D cadastre), which require further attention.

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1. INTRODUCTION

Countries throughout the world are confronted with the complexity of cadastral registration of 3D property units.
A 3D property unit (or 3D real estate object) is a (bounded) amount of space to which a person is entitled by means of real rights. In fact the traditional parcel, with only one person entitled to it, is also a 3D property unit (often not explicitly bounded), however this never has caused any arguments or problems with respect to the third dimension. The problems arise in complex situations, i.e. 3D property situations. 3D property situations are situations in which different property units (with possibly different types of land use) are located on top of each other or constructed in even more complex structures, i.e. engaging one another.
In this paper these types of property situations is referred to as 'stratified property'. In cases of stratified property several users are using an amount of space which is limited in three dimensions and positioned on top of each other, either all within one parcel (the volumes are located in the same volume defined by the surface boundaries) or crossing parcel boundaries. Real rights are established to entitle the different persons to the different volumes.

Developments to face the problems that arise when registering 3D property units in the cadastral registration depend on the national legal system and the state of the art of the cadastral registration in the specific country. For example, in the Netherlands, in which the legal system is based on Civil Law, property right to real estate is still very much land oriented in the juridical and cadastral doctrine, while other countries, as will be seen in this paper, may have legal systems that provide the possibility to establish 3D property units no longer related to surface parcels.

At the TU Delft, the Netherlands a research is being carried out to study the needs, possibilities and constraints of a 3D cadastre (Stoter and Ploeger, 2003; Stoter and Van Oosterom, 2003). This resulted in several conceptual models for a 3D cadastre, which were translated into prototype implementations. The conceptual model that showed best potentials for the long-term future is the full 3D cadastral model. In the full 3D cadastre the basic entity of cadastral registration is no longer a 2D parcel: in the full 3D cadastre persons are entitled to 3D volumes, and not to land parcels, by means of property rights. To evaluate the full 3D cadastre model, we compared the model with cadastral registrations that already faced the registration of 3D property situations in some way or another: Norway, Sweden, Queensland (Australia) and British Colombia (Canada).

In section 2 our proposal for a full 3D cadastre is explained. Section 3 described the results of the four case studies in the selected countries and summarises on the state of the art of 3D cadastral registration in these countries. In section 4, our conceptual model is applied to a

case study in Queensland, in order to show how our proposal can improve 3D cadastral registration. This paper ends with conclusions.

2. CONCEPTUAL MODEL OF A FULL 3D CADASTRE

In a full 3D cadastre, 3D space (universe) is subdivided into volumes partitioning the 3D space. The 3D parcels form a volume partition (no overlaps or gaps in 3D). The legal basis, real estate transaction protocols and the cadastral registration should support the establishment and conveyance of 3D rights. The 2D cadastral map does not exist any longer and therefore does not lay down any restrictions on 3D rights, i.e. 3D rights are not related to the surface configuration.
Real estate objects are defined in 3D. Rights and restrictions are related to volumes. Relationships between two 3D parcels may be necessary to take care of for example the accessibility of a 3D parcels which is not directly connected to the surface.

2.1 Only 3D Parcels or Combination with Parcels Defined by Surface Boundaries?

Two alternative models are distinguished for the full 3D cadastre. The first alternative starts with the conversion of the conventional representation of parcels into the third dimension: a parcel is no longer only defined by the parcel boundary but also by an infinite (or actually indefinite) parcel column that intersects with the surface at the location of the parcel boundary. In the first alternative, two types of real estate objects are distinguished: infinite parcel columns (which still apply in 'classic' 2D situations) and volume properties.
In a complete implementation of a full 3D cadastre (second alternative), the only real estate objects that is recognised by the cadastre are 3D parcels (bounded in all dimensions) and the 3D parcels form a complete partition of space. In the second alternative, it is no longer possible to entitle persons to infinite parcel columns, defined by surface parcel boundaries, but only to well-defined (and totally bounded), surveyed volumes. In this alternative cadastral registration of the whole country is converted into 3D. The question can be posed if a full 3D cadastre that only supports 3D parcels is realistic for cadastral registrations that have a long history and already contain a lot of information that is related to 2D parcels which still suffice in many cases. It requires a total renewal of the cadastre, also in 2D situations, while the first alternative of a full 3D cadastre still has a strong link with current cadastral registration: traditional 2D situations (parcels with only one person entitled to it) can be kept largely unchanged. Therefore, here we only focus on the first alternative.

2.2 Full 3D Cadastre that Combines Parcels Defined on the Surface and Volume Properties

To meet the cadastral needs at a more fundamental level, the concept of 2D parcel should be reconsidered as well as the changing role of cadastral registration. Nowadays cadastral registration not only focuses on the registration of real property (ownership to real estate), but also serves other tasks (used by both private and public sectors in land development, urban and rural planning, land management and environmental monitoring) (FIG, 1995; Williamson, 2001). In the full 3D cadastre the concept of 2D parcels is abandoned and therefore it is possible to register real estate objects with different purposes.

The real estate object in the full 3D cadastre gets a wider meaning. It may include areas or volumes, not necessarily coinciding with (3D) property boundaries of land parcels, e.g. a forest protection zone. This is similar to the term 'legal land object' as defined in (FIG, 1998).

The full 3D cadastre that combines parcels defined on the surface and volume properties starts with the currently registered parcels (that still suffice in many 2D situations), which are converted into infinite parcel columns. In addition to the infinite parcel columns, volume properties are distinguished. These volume properties are actually '3D parcels', but here we follow the terminology of (Lemmen et al., 2003), which denote 3D parcels, as meant here, with 'volume properties'. In this solution, the real estate object can be:

- parcels, representing either infinite parcel columns, or columns of space of which volume properties have been subtracted: these parcels are actually defined in 3D (based on the 2D surface representation);
- volume properties;
- restriction areas (only defined in 2D);
- restriction volumes (defined in 3D).

The UML class diagram of this solution is shown in figure 1 (see also Lemmen et al., 2003).

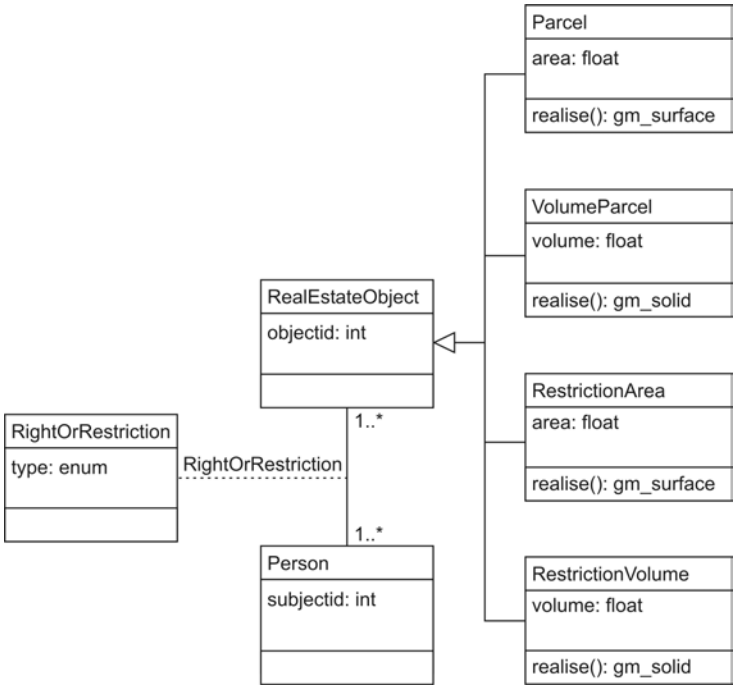

Figure 1: UML class diagram of full 3D cadastre that supports both infinite parcel columns and volume properties.

The collection of the 2.5D surfaces of parcels explicitly covers the whole surface (without overlaps and gaps). This is a very important concept in cadastral registration in order to avoid inconsistencies. A parcel implies the whole 3D column above and below the surface or what

is left after volume properties have been subtracted from the parcel column. The geometry of the volume parcel defines a bounded space in 3D. Consequently a complete space partition is defined by the (infinite) parcel columns and the volume properties. One 3D volume parcel can be established crossing several parcels and several 3D volume parcels can be established above or below one parcel.

Important constraints for the full 3D cadastre are:

- projection of parcels should form a full partition of the 2.5D earth surface;
- volume properties may not intersect other volume properties (in 3D).

Because of the different meaning of restriction areas and restriction volumes, restriction areas may intersect other restriction areas (e.g. a forest protection zone may intersect a ground water protection zone), and restriction volumes may intersect other restriction volumes (e.g. a 3D volume that indicates severe soil pollution may intersect with a volume that indicates the presence of a monument imposed by the Law on Monuments).

To be able to register the parcels, volume properties, restriction areas and restriction volumes in the cadastral registration, all real estate objects must have a survey document, which should make clear what space the real estate object refers to. The 3D information in these survey documents can then be integrated in the cadastral geographical data set, which will be a mix of 2.5D objects (surface parcels and restriction areas) and 3D objects.

3. 3D CADASTRAL REGISTRATIONS ABROAD

When establishing a 3D cadastral registration, several phases can be distinguished. 3D cadastral registration starts with the possibility to establish 3D property units within the juridical framework. The next step is to provide insight into the 3D property units, e.g. by drawings included in the land registration (Public Register describing interests in land) or, even better, or by integrating the 3D information in the cadastral registration (which links the essential information from documents recorded in the land registration to geometry of real estate objects). In a final phase, regulations could be laid down, which define how to prepare and structure the 3D information that is used to maintain 3D property units in the land registration and/or the cadastral registration.

The different countries have been assessed, bearing these phases in mind, by examining the following questions:

- How can 3D property units be established within the existing juridical framework?
- What was the main trigger to establish 3D property units?
- Do 3D property units exist independently in the land registration?
- Do 3D property units exist independently (with 3D geometry) in the cadastral registration, and if so, how (e.g. with link to 3D geometry or integrated in cadastral geographical data set)?
- What are the main shortcomings of current registration of 3D property situations?

3.1 Norway

Norway has a solid subsurface in a geological sense. Tunnels for roads, trains, and water drilled in the subsurface do not influence the economic value of the surface property and are therefore already common practice in Norway without subdivision and formal registration in the cadastre and in the Land Book. The owners of surface properties have only been compensated financially if the surface property has been damaged in any way.

In the beginning of the nineties, providing possibility for 3D property was listed as an important issue for the improvement of cadastral legislation, since the current juridical framework does not provide the establishment of 3D property units with separated ownership on one surface parcel. It was expected that investors are more willing to invest money in registered ownership, than in all kinds of limited rights that are currently used to establish stratified property.

A committee was established in 1995 which concluded that three types of 3D property should be facilitated:

- volumes below the surface of the earth, such as underground parkings, shopping areas, tunnels;
- buildings and other constructions erected on pillars or by other means realised above the original surface of the earth, mostly above roads or railways;
- constructions on pillars at sea or fresh water.

The findings of the committee led to a proposal for a law on *'construction properties*'. It is assumed that this law will be enacted in 2006 (Onsrud, 2002). In this law the surface property is still the basic property object including all land and permanently fixed constructions except what is subdivided from the surface property. It is expected that the chosen legal instruments will have effect on prices.

A 3D construction property has the following characteristics:

- A 3D property can only be established after subdivision from the surface property and may cross several surface parcels.
- It is upon the parties involved whether to use the 3D property construction solution or to use other possible solutions such as servitudes or remaining unregistered in the cadastre.
- The directly involved parties enjoy maximum freedom and carry the risk of making bad arrangements. This means that surveying and mapping is required only in such a way, that the public sector is served satisfactory (for general land administration, city management and taxation). Any detailed surveying is the choice and responsibility of the parties involved.
- Since a new parcel can only be established when it follows the planning and building acts, a subdivision of a parcel in general is not permitted unless it is likely that the subsequent construction on the parcel is approved. This means that there is a direct link between the new parcel and the building to be created. 3D construction properties that

will remain unused are prevented by this regulation. In addition the potentials for speculation in land are reduced. A 3D property construction will only be approved when it is needed to support a particular and approved construction. The law on 3D construction property inhibits therefore the free construction of 3D property units.

- A 3D construction property will cease to exist should the actual construction to which it alludes collapse and not be rebuilt within three years.
- A 3D construction property can only be established when the surface still can be used for a relevant purpose as part of the property from which the construction property will be subdivided. Therefore a building standing directly on the surface cannot be established as a 3D property.
- 3D construction property cannot be established for parts of buildings and is only possible in case of separate buildings in which the 3D properties have no extensive relationships to the neighbouring properties than normal relationships between neighbouring surface properties. In the other cases, apartment rights (eierseksjan) must be used, for example in case the new units are part of a common owned building.

At this moment no specifications for surveying or solutions for the cadastre are part of the proposal, since conditions in this area would only delay the introduction of the law which meets the demand of the market. For the short-term future it is expected that the cadastre will accept rather simple solutions such as visualising the projection of the 3D property on the surface only, referring to more detailed information contained in the deeds.

Awaiting the new law, the municipalities (which are the cadastral authorities on local level) have since many years practiced to establish properties as volumes above and under the surface, subdividing the volume from the surface property. They have extended the existing cadastral law with municipal regulations to be able to divide properties into volumes. The new regulations are based on the existing practices. An example of this practice is the municipality of Oslo. This city introduced a practical approach to register 3D properties as real property both in the cadastral registration and the title register (Valstad, 2003). These properties can be mortgaged and have rights and restrictions as surface parcels. The existing law does not provide these 3D real properties, and hence the Oslo method has mostly been limited to underground facilities.

In case of a 2D subdivision, the new parcel boundaries are surveyed and marked. In the 3D case, it is impossible to survey before the actual construction has been built. Therefore the plans and drawings from the applicant are sufficient. Usually, this drawing is also accepted as the final result on which a survey certificate is issued without any surveying. On the survey certificate each corner is given in co-ordinates and heights both at the floor and the ceiling. The registration number and the survey identify the parcel as a volume, but in the various registers the parcels size is given in square meters and not in cubic metres. This is due to the Land Subdivision Act that has no provision for 3D parcels except in the accompanying text. An underground parcel is identified by a unique parcel number. Underground parcels can be recognised because the parcel number ends with '300'. The numbering of the 3D parcels is done in such a way that the relationships with the surface parcel are preserved.

3.1.1 Evaluating 3D Cadastral Issues in Norway

How can 3D property units be established within the existing juridical framework?
The new law will enable to establish 3D construction properties that may cross surface parcel boundaries. Although construction property is not yet formally allowed, municipalities and the land registration already accept it, as was shown by the Oslo method.

What was the main trigger to establish 3D property units or to start the discussion on how to establish 3D property units?
Before the law will be enacted, stratified property can be established by apartment rights or just by the fact that the owner of the surface parcel is not obstructed in using his property. In the last case, the legal status is not established and not registered, which is always some kind of a risk, especially in case of constructions owned by private persons. Therefore it is required to ensure the legal status of real property in the cadastre. Apartment rights always should relate to a surface parcel on which the related building is erected, while the 3D construction properties are not related to the surface parcels. The 3D construction property enables 3D ownership for which apartment rights are not an appropriate solution such as independent volumes below the surface crossing several surface parcels (underground garages, shopping areas, tunnels etc.) and buildings and other constructions erected on pillars or by other means realised above the original surface (frequently across roads and railways).

Do 3D property units exist independently in the land registration?
The existence of the 3D property units is known in the land registration. However there are no requirements for surveying and mapping the 3D property unit. The 3D geometry of the property unit may therefore not be known (in detail) in the land registration.

Do 3D property units exist independently in the cadastral registration?
The 3D property units exist in the administrative part of the cadastral registration. The footprint of 3D construction properties can be drawn in the cadastral map. However, the 3D geometry of the 3D property unit will not be maintained.

What are the main shortcomings of current registration of 3D situations?
The fist shortcoming is that 3D property units are limited to constructions. Furthermore the cadastral registration can be improved by firstly setting up regulations to survey 3D property units and secondly by solving the technical aspects of 3D cadastral registration: how to incorporate the 3D information in the cadastral map?

3.2 Sweden

Before January 2004, in Sweden the division of ownership in the third dimension was not possible. This has led to remarkable legal structures. For example the space for the Stockholm underground is granted through an easement. The dominant parcel to which the easements are linked is a small property formed for a lift shaft going down to the underground railway (Mattsson, 2003).

Need for 3D property has been very much influenced by the fact that apartment units in an apartment complex can only be owned totally by one housing association. Each apartment owner may sell his net share of the co-operative.
However, only the association may take a loan and the loan can only be secured by a mortgage on the entire property. Consequently, apartment units cannot be mortgaged independently. Difficulties can arise when two types of use are combined in one building (e.g. apartment units and offices), which requires different owners as well as the possibility of mortgaging the parts separately. The separation of these properties would make the apartment units as well as the offices more attractive on the real estate market (the office property will no longer lumber the housing property and vice versa). Therefore, for financial and administrative reasons, there is a need to divide properties in such a way that the facilities or parts of them can be mortgaged separately and owned as separate properties.

(Julstad and Ericsson, 2001) and (Mattsson, 2003) describe a new law which facilitates 3D property units. The law came into force January 2004 (Swedish government, 2004).
The law was prepared by a committee, appointed by the Swedish government in 1994 to investigate the potentials for solving the problems of different types of use in one building. The main conclusion of the committee was that the most appropriate solution would be the possibility to establish 3D property similar to 2D property. 3D properties can then be mortgaged and information on the 3D properties is accessible through the real property register. The main objection which came to the proposal was that the fundamental property concept should not be altered from 2D since the cases of 3D are limited. Therefore the new 3D properties had to fit within the structure of 2D properties. The following criteria have been set up for 3D properties (*3D-fastighet, 3D-utrymme*):

- Title must be in perpetuity
- Title shall, as far as possible, be independent of the (land) property within whose parcel column it is located and shall be separately transferable, without any simultaneous transfer of the surface land
- A 3D property must be an object for credit; public authorities, credit providers and other outsiders shall have the possibility to obtain information on the rights established on the property
- The new rules should as far as possible be in accordance with the existing principles of real property law
- The ultimate aim of 3D property formation is to create better opportunities for 3D property use and also for such properties to be capable of serving as security for the grant of credits

3D property formation is only permitted if it accommodates, or intends to accommodate, a building and if it is assured of the rights necessary to its appropriate use (e.g. rights for joint facilities, easements). To avoid empty airspace property units, the 3D property has to relate to a real construction. When it is related to a construction to be built, the cadastral authority can set a deadline for the completion of the construction.
Unlike in Norway a building itself may be divided into different property units. This is also the main type of ownership situation that the new law wants to facilitate. However, a 3D property for housing purposes should contain at least five apartment units, which means that

the new legislation does not afford scope for the creation of apartments. The 3D property units may intersect boundaries of surface parcels and cover multiple parcels on the surface.
The 3D property is registered in the real property register and therefore accessible to the public. The new law takes only care of the legal issues, cadastral issues (how these constructions should be documented, how they are to be registered or how they will be made visible on the cadastral map) still need to be solved. At this moment the projection of the 3D property units can be indicated on the cadastral map.

3.2.1 Evaluating 3D Cadastral Issues in Sweden

How can 3D property units be established within the existing juridical framework?
The new law enables to establish 3D property units that may cross surface parcel boundaries, and must be related to constructions.

What was the main trigger to establish 3D property units or to start the discussion on how to establish 3D property units?
The main problem of the existing juridical system is that apartment units cannot be mortgaged independently, which may obstruct investors to invest in multi-purpose building complexes.

Do 3D property units exist independently in the land registration?
The 3D property units are registered in the land registration. However there are no requirements for surveying and mapping the 3D property units. The 3D geometry of the property unit may therefore not be known (in detail) in the land registration.

Do 3D property units exist independently in the cadastral registration?
Although 3D property units are registered as independent property units in the administrative part of the cadastral registration, it is not yet clear how 3D property units will be documented as part of the cadastral geographical data set. At this moment the projection of 3D property units can be drawn on the cadastral map.

What are the main shortcomings of current registration of 3D situations?
As in Norway, the first shortcoming is that 3D property units have to relate to constructions. And also in Sweden the cadastral registration can be improved by setting up regulations to survey the 3D property units and by solving the technical aspects of 3D cadastral registration: how to incorporate the 3D information as part of the cadastral geographical data set?

3.3 Queensland, Australia

In Queensland, Australia, the 3D registration has (partly) been solved. Since 1997, it is possible to create parcels with 3D geometries. The juridical framework of Queensland, which originated from Common Law, provided the possibility of establishing 3D property units (which can be both freehold and leasehold estates). However, the cadastre does only include the footprint of these 3D parcels on the cadastral map, and therefore the cadastral issue of 3D property units (giving insight in the 3D property situation and register rights on volumes) is not solved in Queensland, Australia.

3.3.1 Restricted Parcels, Building Parcels and Volumetric Parcels

According to the Land Title Act of Queensland (Queensland, 2003), a standard parcel (defined in 2D, but implying the 3D column) is a lot (or a collection of lots) which are unlimited in height and depth. Apart from these 'unrestricted' parcels, four parcels with a 3D component are distinguished:

- Building parcels, which are parcels that are generally defined by floors, walls and ceilings;
- Restricted parcels, which are parcels restricted in height or depth by a defined distance below the surface or by a defined plane (restricted easements can also be restricted in height and depth): the boundaries of the restricted parcels coincide necessarily with the boundaries of the surface parcel;
- Volumetric parcels, which are parcels that are fully limited by bounding surfaces and are therefore independent of the 2D boundaries of the surface parcels;
- Remainder parcels, which are parcels that remain after a volumetric parcel or building parcel have been subdivided out of it.

The 'in strata' parcels that were used before 1997 (and are not applied any more) both included the volumetric parcels and the restricted parcels.

A standard parcel may be subdivided using three different formats of survey plans: standard, building or volumetric format.
In the document "Registrar of titles, directions for the preparation of plans" (Queensland, 2003b) the conditions of the different plans are exactly described.

A standard format plan defines land using a horizontal plane and references to marks on the ground.
A standard format plan is used for standard parcels and restricted parcels. In case of standard parcels, the drawn parcel refers to the whole parcel column.
Restricted parcels (which are restricted in height or depth) are also indicated on standard format plans by *values relative to the surface* (defining horizontal planes), or by a defined plane. Restricted easements are also established by means of standard format plans. However, for easements the vertical restriction shall be detailed on the plan with reference to the Australian Height Datum together with details of the Permanent Mark on which this is based (page 20 of Queensland, 2003b).

A building format plan defines land using the structural elements of a building, including floors, walls and ceilings (building parcels). A building format plan is used in situations similar to apartment units in the Netherlands. A parcel is subdivided into minimal two building units (lots) and a common property (that is shared). The common property is linked to the units and not to the persons owning the units.
Lot numbers in buildings shall be numeric and may be made up in the form FL, TFL or TL, where T is a tower number, F is a floor number and L is the lot number.

The building format plan should include a main plan with the location of each building or structure with respect to the outer boundaries of the case parcel (i.e. the projection of the outermost walls of the building), inclusive any sub-surface basements and a diagram of every level of the building showing the parcels and common property on that level (page 32 of Queensland, 2003b). The maximum amount of encroachment (building intersects with other parcel) permitted is limited to half the width of the wall (page 36 of Queensland, 2003b). Consequently "the boundary of a Building Format lot may not be projected beyond the boundaries of the base parcel".

A volumetric format plan defines land using 3D points to identify the position, shape and dimensions of each bounding surface and is used to reflect volumetric parcels. A volumetric parcel is a parcel, which is fully limited by bounding surfaces (which may be other than vertical or horizontal) and are above, below or partly above and partly below the surface of the ground (compare with restricted parcels and notice the difference). Volumetric parcels are possible in Queensland under the Land Title Act since 1997. The use and purpose of volumetric parcels (not per se related to constructions e.g. for view shed) are determined by the Local Government and other legislation.
One volumetric parcel can be established intersecting several parcels. All lines on a volumetric format plan are straight and all surfaces are flat, unless explicitly stated otherwise, hence any surface which is mathematically definable (so that an intersection can be calculated) can be registered.

The height used to define volumetric parcels cannot refer to above or below a depth from the surface (the height cannot be defined as relative height or depth) since "this is subject to change and not capable of mathematical definition". The corners of volumetric parcels should refer to existing structures or marks as much as possible. The vertices of the corners should be given in polar dimensions (and optionally in rectangular co-ordinates) and levels on the Australian Height Datum. Each volume shall be given an area, which is the area of a footprint, and a volume in cubic meters. The plan should show a 3D representation of the parcel. The 3D descriptions are maintained in titles in the land registration while a footprint of the volumetric parcel is shown on the cadastral map.

The cadastral geographic data set of Queensland has a "base layer", which is a complete non-overlapping coverage, and consists of parcels, road, rail, watercourse and intersection parcels. An intersection parcel is part of a roadway (the intersection of two roads or railway or water). Volumetric parcels are not part of the non-overlapping coverage, but the footprint of these 3D parcels is drawn on the cadastral base layer and therefore they are overlapping with the base parcels. Also easements, having their own geometry (and survey plans), are drawn on the base layer and may therefore intersect several parcels (initially easements are defined on a single base parcel, but the base parcel may get subdivided, leaving the easement whole). Building parcels are not drawn on the cadastral map.

3.3.2 A Case Study in Queensland

Since volumetric and restricted parcels are advanced examples of 3D property units, a case study from practice will be used to illustrate the establishment of these parcels: the

establishment of 3D property units for the Gabba Cricket stadium in Brisbane. This stadium overlaps two streets: Vulture Street in the north and Stanley Street in the south (see figure 2).

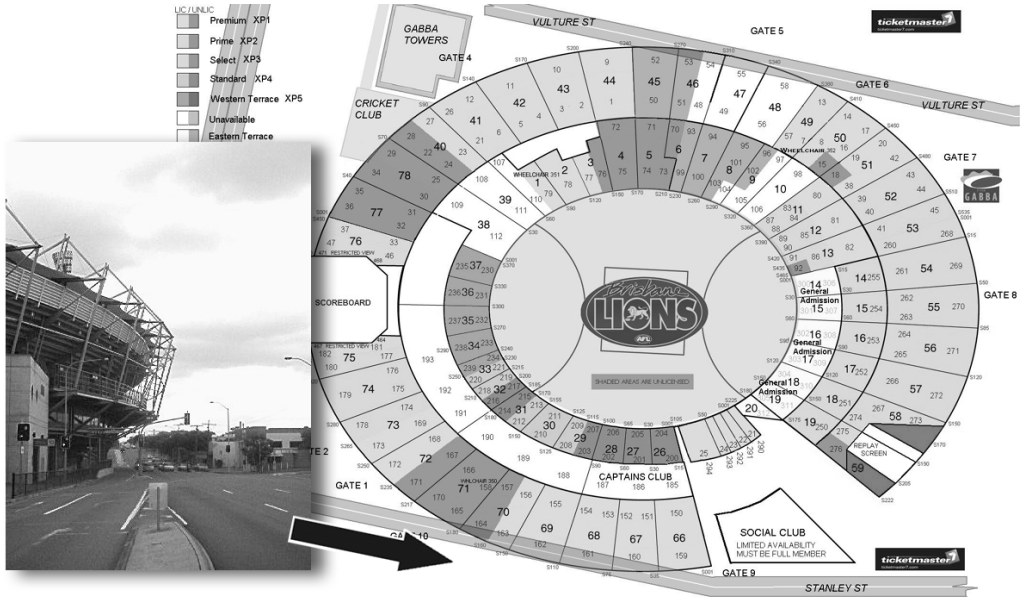

Figure 2: Overview of Gabba Stadium overhanging Stanley Street in the south and Vulture Street in the north, Brisbane, Australia.

Three 3D properties have been established: for the intersection with Vulture Street a stratum with parcel identifier 100 (established before 1997) and a volumetric parcel with identifier 101 and for the intersection with Stanley Street a volumetric parcel with identifier 103. The volumetric parcels have been established after 1997. All three parcels are leasehold estates. This means that the holder of the real estate has the right of use and exclusive possession of the property for a specified time, which is comparable to the right of long lease. However it should be noted that most volumetric parcels are related to freehold estates.

The titles establishing the 3D parcels contain very detailed 3D information imposed by the regulations: cross sections are added in case of the strata title and 3D diagrams are added in the titles for the volumetric parcels (see figure 3 for parcels 101 and 103). All coordinates that are needed to demarcate the 3D property are present in the titles in polar coordinates (and not in rectangular coordinates). The height of all coordinates is defined in the Australian Height Datum.

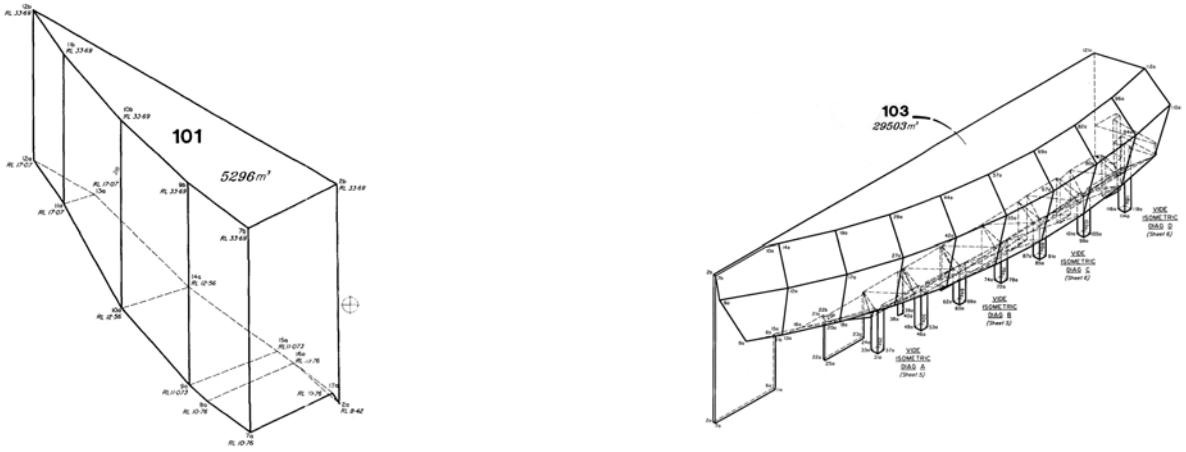

Figure 3: Examples of 3D diagrams added to volumetric titles (parcel 101 and 103).

The footprints of the 3D properties are part of the cadastral geographical data set. Figure 4 (a) shows the cadastral map with the footprints of the 3D parcels and figure 4 (b) shows the cadastral map without the footprints of parcels 100, 101 and 103 (and without the geometry of easements). This shows that 3D parcels are not part of the base parcel map and that volumetric parcels (and traditional strata parcels) exist separately from the base map and may therefore intersect parcels of the base parcel map. For example 3D stratum title of parcel 100 does cross two parcels on the base map.

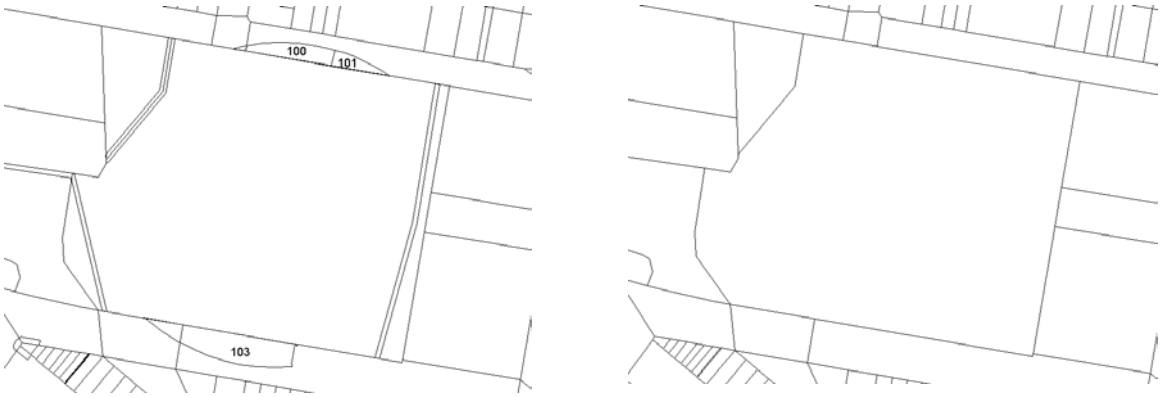

Figure 4: Cadastral map with (and without) footprint of 3D parcels (100, 101 and 103) (and easements)

This example shows the very good potentials of establishing 3D properties in the current registration in Queensland. How 3D information, which is part of survey plans and (volumetric) titles, could be further used to improve cadastral registration, will be explained in section 4, where the concepts developed as part of the 3D cadastre research are applied in a prototype to this case study.

3.3.3 Evaluating 3D Cadastral Issues in Queensland

How can 3D property units be established within the existing juridical framework?
3D parcels (either bounded or unbounded) can be established. The way Queensland has solved the 3D property problem, gives the impression that the existing law was flexible enough to provide for the establishment of 3D parcels.

What was the main trigger to establish 3D property units or to start the discussion on how to establish 3D property units?
The existence of constructions on top of and engaging each other asked for the possibility to establish different ownership on top of each other. The legal system was flexible enough to be extended to provide for 3D property units and the cadastral registration followed the legal practise.

Do 3D property units exist independently in the land registration?
The 3D property units (bounded and unbounded parcels) are known in the land registration. The 'Registrar of Titles directions for the preparation of plans' dictates how to incorporate 3D information in survey plans. In case of restricted parcels, the project parcels with values relative to the surface are sufficient, while volumetric survey plans require 3D diagrams, including values in the Australian Height Datum. It should be noted that the survey plans are (scanned) drawings. It is therefore not possible to view the volumetric parcels in an interactive 3D environment.

Do 3D property units exist independently in the cadastral registration?
3D property units exist in the administrative part of cadastral registration. The footprint of the volumetric property is drawn on the cadastral map, and is therefore known in the cadastral registration. However, the 3D geometry is not available in the cadastral geographical data set, and therefore it is not possible to query the 3D situation from the cadastre, nor is it possible to see if two volumetric parcels overlap.

What are the main shortcomings of current registration of 3D situations?
Although, the titles contain detailed 3D information, the registration of the 3D properties meet some complications due to a number of reasons:

- Since the 3D information is laid down on paper (or scanned) drawings (which is a 2D visualisation), the 3D information cannot be interactively viewed. This is a weak point because the ability to do so may be very helpful in case of complex volumetric parcels to interpret the situation correctly (e.g. parcel 103).
- The 3D properties are only described by coordinates and edges on drawings, i.e. no 3D primitive is used. Therefore it is not possible to check if a valid 3D property has been established (is the 3D property closed, are the faces planar, no crossing edges and faces).
- The 3D information is not integrated with the cadastral map or with other 3D information, e.g. two or more neighbouring parcels cannot be visualised in one view in 3D and it is also not possible to check how volumetric parcels spatially interact in 3D (overlap, touch etc.).

In Queensland, the basic improvement for 3D registration would therefore be to incorporate the information on 3D property units, which is already very well described in survey plans in the land registration, into the cadastral registration.

3.4 British Colombia, Canada

In British Columbia in Canada an owner of a parcel has the right to subdivide his land into air-space parcels according to section 139 of the Land Title Act (British Colombia Government, 1996).
The air-space parcel may continue, or exist completely below the surface as well.
Only the 'fee simple estate', which consists of all ownership rights that can be attached to a certain parcel (complete ownership), can be subdivided and not a leasehold estate (which is an estate created between a landlord and a tenant under a contract, comparable with the right of long lease in the Netherlands).

For every subdivision, also in 2D, a subdivision plan has to be made. For air-space parcels a special part of the Land Title Act applies.

Every new 3D parcel (air-space parcel) has to be created within an existing conventional parcel. The grant of an air-space parcel does not transfer any easements that limits the use of the grantor's land. The title to the ground below and the air-space above and below the granted air-space parcel remains the possession of the grantor. This means that an easement has to be created separately if access to the newly created air-parcel is desired.

The main requirement for creation of an air-space parcel is the provision of an air-space plan on the belonging title (British Colombia Government, 1996b). This plan must consist of a 3D drawing to show that the boundaries lie within the boundaries of a single parcel (figure 5). This raises the question what will happen if the surface parcel is subdivided later on. The plan must further indicate if it is a subdivision of the whole parcel shown on the plan or just a part thereof.

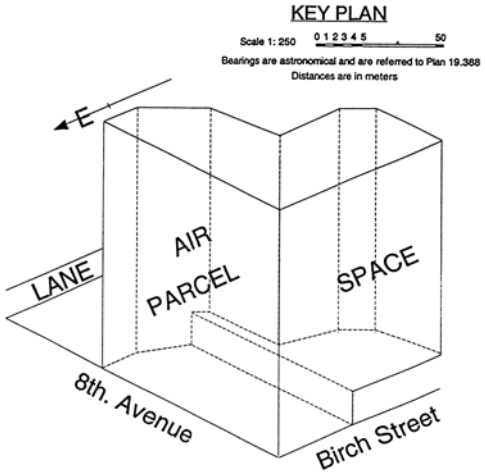

Figure 5: Drawing in title of air-space parcel (taken from, Gerremo and Hanssen, 1998)

A geodetic elevation (absolute value) is needed which must be noted on at least one of the corners of the parcel on the ground and for every corner or angle of the subdivided air-space parcel. Air-space parcels can be used for stratified property, but also for the purpose of later granting a right of view to benefit a parcel next to a planned construction (Gerremo and Hanssen, 1998) .

For a further division of the air-space parcel, the rules of the Condominium Act applies. This divides the air-space into strata lots or 'flying fees'. The Condominium Act states that a building or land may be subdivided into strata lots by the provision of a building strata plan. The strata lots are coupled with an interest as a tenant in the remaining common areas. It is possible to either establish freehold or leasehold condominiums. The new strata lots have the same status as any land that is registered at the Land Title Office. The strata plan must contain a diagram of the proposed project, showing the boundaries of the land included in the strata plan and the location of the buildings.

In British Colombia the survey plans are registered in the Crown Land Registry and in the Land Titles Office. The Crown Land Registry lists all Crown land converted to private ownership, all private land turned over to the government, all existing Crown land tenures, leases, licences, or other time-limited holdings and includes maps that record the location of Crown land parcels. In British Colombia the Crown owns ninety percent of the land. The remaining ten percent is privately owned (Gerremo and Hanssen, 1998). In the Land Title System, all titles are given a parcel identifier number, which is part of the legal description and should be included in all land titles documents. A registered title for a 'fee simple estate' can either be a conventional parcel or an air-space parcel, which are both considered as land under the Land Title Act. It can also be a part of the building, i.e. a strata lot according to the Condominium Act.
There is no general map which covers all existing parcels. There is only a plan that defines the specific area. Therefore information on the 3D (and 2D) properties can only be found in the land registration in the title documents. One has to look in the survey plans to get insight in the juridical situations.

3.4.1 Evaluating 3D Cadastral Issues in British Colombia

How can 3D property units be established within the existing juridical framework?
3D property units with separate ownership are allowed since it is possible to establish air-space parcels, apart from conventional parcels and apart from lots that are the results of subdivision under the Condominium Act.

What was the main trigger to establish 3D property units or to start the discussion on how to establish 3D property units?
As in the case of Queensland, the existence of constructions on top of and engaging each other asked for the possibility to establish different ownership on top of each other. Also in British Colombia the legal system was flexible enough to be extended to provide for 3D property units. The cadastral registration follows the legal practise.

Do 3D property units exist independently in the land registration?
The 3D property situations are indicated with 3D diagrams in survey plans and can be known from the documents and records in the land registration.

Do 3D property units exist independently in the cadastral registration?
In British Colombia, the cadastral registration is actually the land registration which includes a title registration. The survey plans are maintained as part of the titles. However there is no cadastral map in British Colombia. In 2D, neighbouring parcels cannot be integrated in one view, by which it is hard to get an overview of a certain situation and to see if two parcels overlap. Consequently, air-space parcels can also not be shown in one integrated view with other (air-space) parcels.

What are the main shortcomings of current registration of 3D situations?
Since 3D survey plans are prepared (more or less) in a similar way as in Queensland, basically, the same shortcomings apply.
In addition, the 3D cadastral registration in British Colombia would be improved by two major steps. The first step is to make 2D survey plans digital and to create one parcel map out of the plans, with no overlaps and gaps in 2D. The second step is to make 3D survey plans digital (to be able to view the 3D property units interactively and to check the 3D property units) and to include the 3D information that is in detail available in survey plans in the digital cadastral data set. This would make it possible to query the air-space parcels in a combined view with the cadastral geographical data set.

3.5 Conclusions on 3D Cadastral Registrations in Four Selected Countries

In the selected countries it is, or will be soon, possible to establish 3D property units with separate ownership no longer related to the surface parcels, within the existing juridical framework (with some extensions).

These solutions differ per country, e.g. the footprints of 3D property units are limited to the 2D surface parcels (British Colombia) or not (Norway, Sweden, Queensland), the 3D property units have to relate to built constructions (Norway, Sweden) or not (British Colombia, Queensland), the 3D property units have to be described in survey plans (British Colombia, Queensland) or not (Norway, Sweden).

However none of these solutions is a complete solution for 3D cadastral registration. Firstly, a digital description of the 3D property unit in vector format is not maintained (only scanned or paper drawings) in the land registration. Therefore the 3D property unit cannot be viewed interactively and the geometry of the 3D property unit cannot be checked. Secondly, the 3D properties are still not incorporated in 3D in the geographical data set of the cadastral registration, by which it is not possible to query the 3D situation.

These solutions therefore do not address technical issues, such as how to store, query and visualise 3D property objects (in 3D) and how to make sure that 3D properties do not overlap (the condition that 2D parcels may not overlap assure complete and consistent registration in current cadastres).

In the next section, the conceptual model of the full 3D cadastre is applied to the case study in Queensland, to evaluate our conceptual model of a full 3D cadastre and to show the potentials of the solutions that were found in the selected countries.

4. CONCEPTUAL 3D CADASTRAL MODEL APPLIED TO CASE STUDY IN QUEENSLAND

The juridical frameworks in the countries described in the case studies, provide a good basis for the full 3D cadastre. Within these frameworks it is possible to establish property rights to entitle persons to a volume parcel that is no longer related to surface parcels. However, the cadastral frameworks in these countries do not provide the possibility to register the 3D geometry of the volume parcels in the cadastral registration.

To improve cadastral registration we applied the full 3D cadastre concept to the described case study in Queensland, the Gabba Stadium in Brisbane at the location of Vulture Street (in the north), i.e. parcel 100 (stratum parcel) and parcel 101 (volumetric parcel). The required survey plans for the volumetric parcel and the stratum parcel contain 3D information that can be used to describe the 3D geometry of these objects in the cadastral DBMS.
The following steps were followed to convert the spatial information on the (scanned) 3D survey plans into the geometrical primitive in the DBMS:

- The field measurements, as indicated on the survey plan by distances and bearings betweens the successive points, were adjusted by traverse adjustment for each parcel in a local coordinate system;
- The local rectangular coordinates are fitted to the (global) map coordinates by an over determined conformal (Helmert) transformation using three connections points in both coordinate systems;
- The faces were constructed with references to nodes;
- This information was inserted in a self-implemented 3D geometrical primitive in the DBMS (see Arens et al., 2003; Stoter and Van Oosterom, 2002), by which the 3D geometry can be (spatially) queried.

For the implementation in the DBMS, we use Oracle Spatial 9i and we use MicroStation Geographics (Bentley) to access the information.
After these steps the 3D geometries could be visualised and queried in one integrated view (see figure 6), which offers major improvements. It is now possible to see if and how the 3D geometries interact and to view the 3D situation interactively.

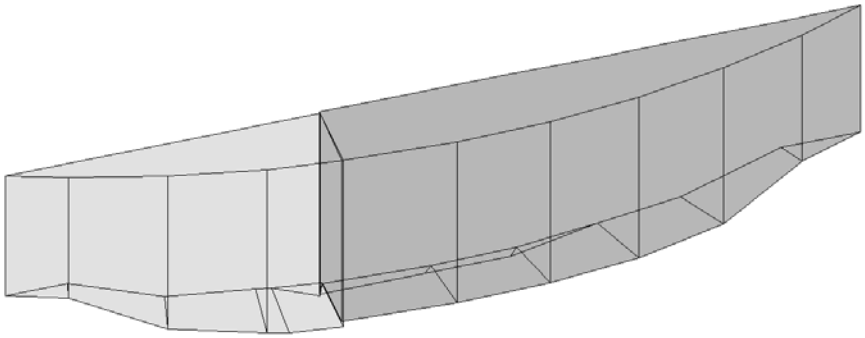

Figure 6: Visualisation of 3D geometries of volumetric parcels, stored in DBMS.

The integrated visualisation of both geometries makes it possible to examine how the two objects interact. In this case the neighbouring faces do not coincide (see figure 7). This may indicate an error but could also be the real case.

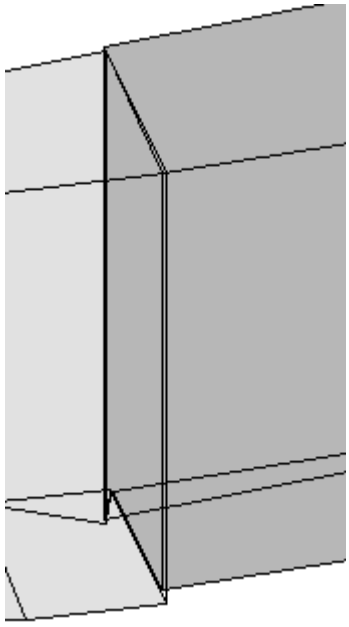

Figure 7: Zoom-in on figure 6 shows that shared faces do not coincide.

In order to validate the volumetric objects and to perform 3D functions on the objects, the geometry of the 3D objects were stored using a self-implemented 3D geometrical primitive (Arens et al., 2003). Therefore we were able to query the 3D objects in an integrated DBMS environment:

```
/* validate of 3D geometries */

select bid, validate_polyhedron(return_polyhedron(shape), 0.5) validate
from qld_3Dgeom;

BID   VALIDATE
```

```
----  ----------
100   True
101   True


/* calculate volumes of 3D geometries

select bid, volume(return_polyhedron(shape)) volume
from qld_3Dgeom;

BID   VOLUME
----  ----------
100   12725.1989
101   5329.18583


/* check if two geometries intersect (1=TRUE and 0=FALSE) */

select intersection(
(select return_polyhedron(shape) from robject3dql where bid=100),
(select return_polyhedron(shape) from robject3dql where bid=101),
0.01) intersect
from dual;

INTERSECT
----------
1
```

The 3D geometries can be incorporated in a cadastral geographical dataset that contains surface parcels represented in 2.5D in order to get a 3D overview of the complete situation. For this purpose a conformal TIN (Triangular Irregular Network) was generated (using ESRI software) that incorporated the planar partition of the cadastral base map (Stoter, Penninga and Van Oosterom, 2004). The result is shown in figure 8.

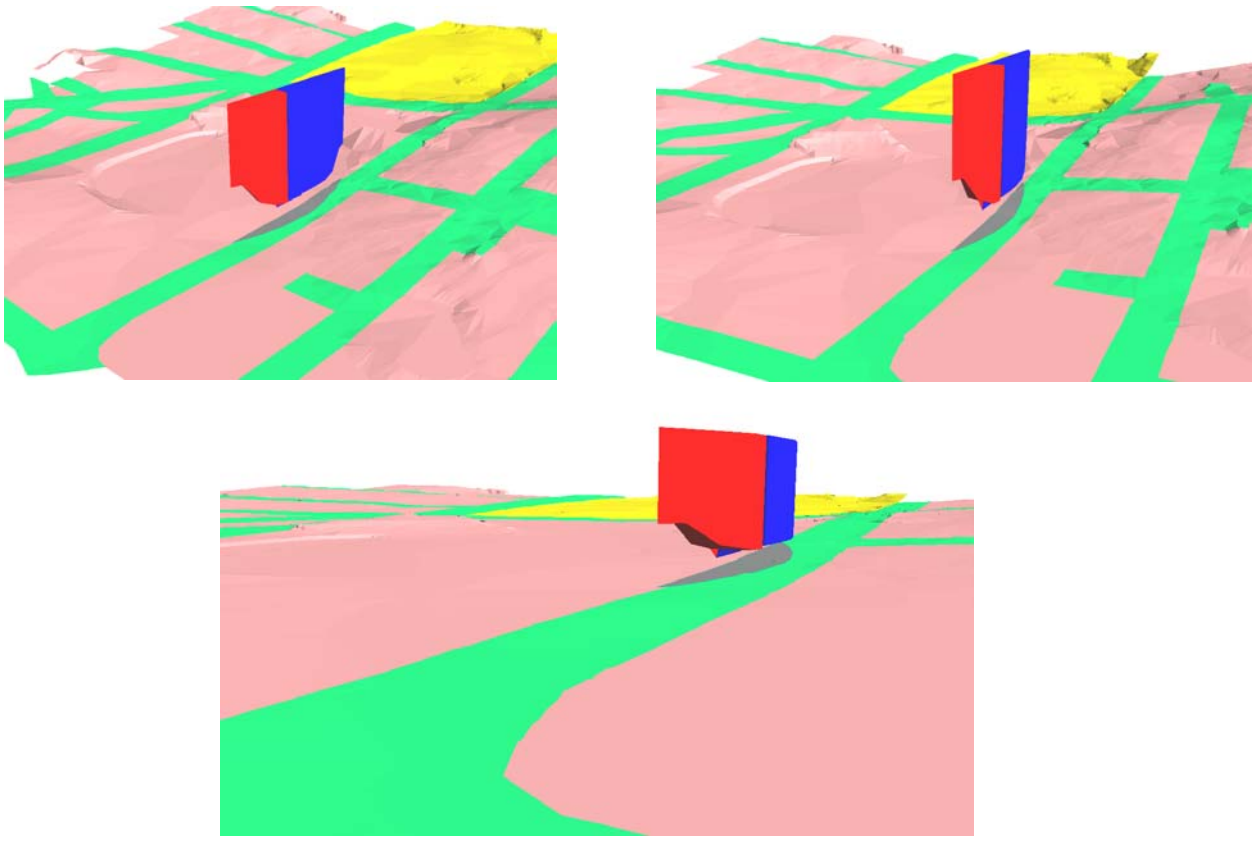

Figure 8: Visualisation of 3D geometries of volumetric parcels together with the 2.5D cadastral base map.

As can be concluded from this case study, the full 3D cadastre offers many improvements compared to traditional cadastral registrations:

- the real situation is no longer projected on the surface, i.e. volumetric parcels are not dominated by the parcel pattern on the surface;
- persons can be entitled to space in a transparent way (instead of establishing property rights on intersecting parcels) ;
- the space is precisely described in a 3D survey document, which offers a uniform way of defining volumetric parcels;
- the information from the 3D survey document can be used to insert the volumetric parcels in a topological structure and using geometrical primitives in the DBMS;
- the volumetric parcels can be viewed interactively;
- the geometry of volumetric parcels can be checked, e.g. are the faces planar?;
- the 3D situation can be (spatially) queried in the DBMS (e.g. do volumetric parcels intersect?);
- the 3D objects and the 2.5D surface parcels can be queried in the DBMS (e.g. is 3D object located above, below the surface, or a combination of both or even include touching the surface?);

- the volumetric parcels can be visualised and viewed in an integrated view with a 2.5D representation of the parcels that are defined by parcel boundaries on the surface.

The advantage of having the 3D real estate objects in the same environment as the 2D parcels clearly offers great potentials. However, even starting from one of the more advanced environments (Queensland, where both the legal aspects and the 3D survey document are satisfactory dealt with) quite a number of non-trivial issues still need to be addressed:

- In the survey plans both the 3D points and edges are specified (as required), however there is no explicit listing of faces (and the polyhedron itself). It is not trivial to reconstruct the faces (and it is possible ambiguous), especially in more complex cases, such as parcel 103.
- The validation of the polyhedron is non-trivial (especially if it consists of other faces than horizontal, vertical or triangular faces): is the volume completely closed, are all the faces planar (enough), is the orientation correct (inside/outside), are holes or cavities modelled correctly, etc.
- In our opinion the coordinates on the survey plans (of parcels 100 and 101) are not given in polar or rectangular coordinates (as required by the directions), but in bearings and distances between successive points in the traverse (this is just a small detail).
- The loop of points defined via bearings and distances does close. However, comparing the common boundary between parcel 100 and 101 (assuming that the two 3D parcels share one common boundary) it shows a difference of about 60 cm in a distance of about 10 m. This difference cannot be explained by the given information but adjustment can be obtained by fitting one polygon towards the other;
- The (footprints of the) 3D objects do not fit perfectly in the cadastral map: making parcels 100 and 101 neighbours, followed by a straightforward conversion from the local coordinates to the map (rotate, translate) resulted in a mismatch of about 60 cm: additional field measurements are required to solve these differences.
- The Queensland regulations also allow non-polyhedral 3D objects, such as (rotated) ellipsoids or cylinders (see figure 9). Should these be converted to polyhedrons (approximation within given tolerance) or should the DBMS be extended with complex 3D data types?
- How to make sure that two polyhedra do not overlap in 3D space (but at most touch in a common node, edge or face) or how to make sure that there is no 3D sliver between two polyhedra that are supposed to be touching neighbours?
- How to organise the cadastral registration in a uniform manner? In the case study (with only three 3D objects al related to the same construction) some differences are noticeable:
  - Neighbour parcels 100 and 101 are both on the same side of the stadium, but parcel 100 is related to a stratum parcel, since it was established before 1997, and parcel 101 related to a 3D volumetric parcel, which are only possible after 1997.
  - Parcels 101 and 103 are both volumetric parcels, while parcel 101 is relatively rough, it seams that parcel 103 is defined quite tight around the construction (making this object quite complex).

– How to avoid trivial registration errors, such as the recording of the volume. It turned out that the recorded volume of parcel 101 in the cadastral registration was not correct (10000 times too large), probably due to some typing error (because the survey plan was correct).

In addition to this, it is also a challenging task to integrate a terrain elevation model with the 2D surface parcels in order to obtain a 2.5D surface parcels which can be combined with the 3D objects. This should be considered an integrated 'view' (in the DBMS sense) on the two data sets from the (independent, distributed) sources and not a physical (permanent) integration. However, this is a topic in itself (Stoter, Penninga and Van Oosterom, 2004) and not discussed in detail in this paper.

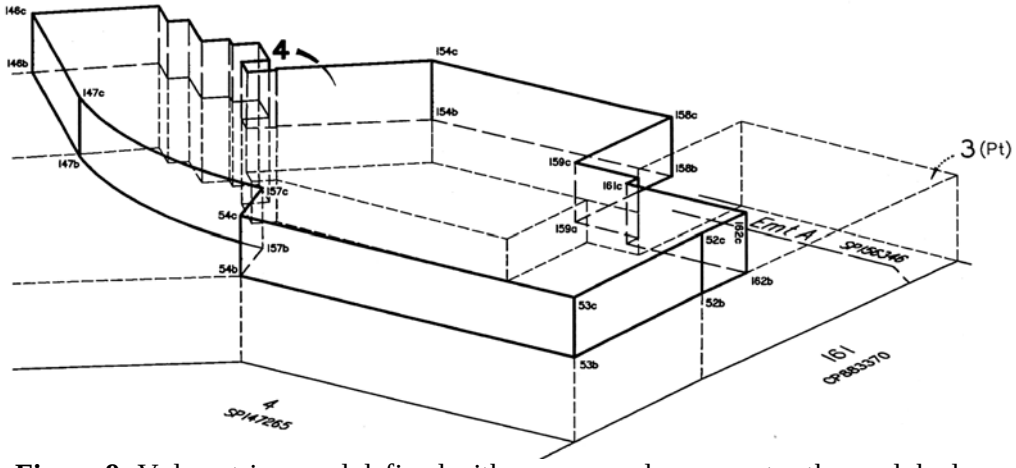

Figure 9: Volumetric parcel defined with more complex geometry than polyhedron.

5 CONCLUSIONS

In this paper we presented two variants of a full 3D cadastre model (developed based on the needs of and in cooperation with the Netherlands' Kadaster): one with only explicit 3D parcels and one with also infinite 3D columns defined by the 2D surface parcels from which explicit 3D parcels may be subtracted. The advantage is that the second model variant has a strong link to the current 2D registration and conversion is more feasible. The second model also has the advantage of being able to represent infinite (open) 3D columns. It was therefore decided to select and refine this model.

The full 3D model was evaluated by comparing it to the cadastral registrations in a number of countries and states (Norway, Sweden, Queensland and British Colombia) that already faced the registration of 3D properties because the different juridical frameworks in these countries provide options for doing so. However, in none of the countries the 3D properties are incorporated into cadastral base map (at best footprints).
It can be concluded that, though the countries have some remarkable differences (some require real constructions to be related to the 3D property registration others not, some limit the 3D property to be within the column of one surface parcel others not, some require quite detailed 3D survey plans to support the 3D property registration others not,...), they all can be supported by a cadastral registration based on our full 3D cadastre model.

The Queensland (Australia) situation seams to be the most appropriate to take the next step towards a true 3D cadastral map. In our 3D cadastre prototype environment (based on a 3D polyhedron extended version of the Oracle spatial DBMS and ESRI and Bentley GIS/CAD software), the 3D property survey plans were converted into a representation in the DBMS and the surface parcels were successfully merged with a terrain elevation model and also loaded in the DBMS. This environment offers the possibility to query, analyse and visualise the true 3D situation of the properties. Roughly stated this paper showed that both the legal, organisational and technical aspects of a 3D cadastre have been solved. It is therefore expected that in the near feature more countries and states (including the Netherlands' Kadaster) will implement (further) steps in the direction of the full 3D cadastre model as described in this paper. It should also be noted that there are non-trivial aspects (in the conversion and use of a 3D cadastre), which require further attention.

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BIOGRAPHICHAL NOTES

Jantien Stoter (MSc) graduated in Physical Geography in 1994. She started her career as a GIS specialist/consultant, with the District Water Board of Amsterdam and Surroundings (1995-1997). From 1997 till 1999 she worked as a GIS specialist/consultant at the Engineering Office Holland Rail Consult. Since 1999 she is an assistant professor in GIS applications, section GIS technology, Delft University of Technology. Also doing a Ph.D. on 3D cadastres. In this research the needs, possibilities, and constraints are studied for 3D cadastral registrations. The emphasis of the research is the implementation of the facility to incorporate 3D real estate objects (geo-objects) in the current 2D geo-DBMS of the Netherlands' Kadaster.

Peter van Oosterom obtained a MSc in Technical Computer Science in 1985 from Delft University of Technology. In 1990 he received a PhD from Leiden University for this thesis "Reactive Data Structures for GIS" (updated version published by Oxford University Press, 1993). From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague, The Netherlands as a computer scientist. From 1995 until 2000 he was senior information manager at the Netherlands' Kadaster, were he was involved in the renewal of the Cadastral (Geographic) database. Currently, professor
Peter van Oosterom is head of the section 'GIS Technology' at the Delft University of Technology, OTB. His main research themes are spatial database management systems, GIS

architectures, generalization, spatial analysis, querying and presentation, Internet/interoperable GIS and cadastral applications.

Hendrik Ploeger studied law at Leiden University. In 1997 he finished his PhD-thesis on the subject of the right of superficies and the horizontal division of ownership rights (Horizontale splitsing van eigendom, Leiden 1997). The same year he did research at the E.M. Meijers-Institute of Legal Studies on the subject of bored tunnels and the rights of landowners. After an assistant-professorship in civil and notary law at Leiden University, he is since 2001 assistant-professor at Delft University of Technology , OTB, section Geo-information and Land management. He is also chairman of the FIG working group on 3D-Cadastres.

Henri Aalders graduated from the Delft University of Technology (DUT) in Geodesy. Since then, he worked in photogrammetry and digital cartography at ITC and digital cadastre at the Netherlands' Kadaster. In 1988 he was appointed as associated professor in land information at the DUT and in 1995 as part-time professor at the Katholieke Universiteit Leuven in Belgium. In 2003 he was appointed as chairperson of CEN/TC 287 for the standardization of Geographic Information in Europe and as vice chairman of the standardization commission of the International Cartographic Association.

CONTACTS

J. E. Stoter
P. J. M. van Oosterom
Hendrik D. Ploeger
Henri Aalders

Section GIS technology
Delft University of Technology
Delft
THE NETHERLANDS
Tel + 31 15 2784268
Fax + 31 15 2782745
Emails: j.e.stoter@otb.tudelft.nl
oosterom@otb.tudelft.nl
h.ploeger@otb.tudelft.nl
h.aalders}@otb.tudelft.nl