Aspects of a 4D Cadastre: A First Exploration

Peter VAN OOSTEROM, Hendrik PLOEGER and Jantien STOTER, the Netherlands
Rod THOMPSON, Australia, and Christiaan LEMMEN, the Netherlands

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SUMMARY

Research in the past years has shown that a 3D registration of information on land in cadastral systems can offer significant advantages for the legal security of real estate. It improves insight into rights and restrictions related to constructions and properties in 3D configurations, of which on top/below each other are the most straightforward examples (Stoter and van Oosterom, 2006). However next to the spatial (3D) aspect of rights and restrictions, the temporal aspect, the fourth dimension of interests in real estate, is an important aspect of cadastral registration. Rights, responsibilities and restrictions have a temporal element. A further category of examples of the need for 4D cadastral information is when a record of history is required on a certain property or when history information on land use development in a certain area is needed to support future land policy; this is the real world time aspect. The final category is where a history of the database content is needed; this is the system time aspect (van Oosterom, Maessen, and Quak, 2002).

It is clear that time has always played an important role in cadastral systems, but so far this temporal aspect has been treated quite independently from the spatial (2D or 3D) aspect. The current cadastral systems deal with both 3D situations and temporal 4D aspects on an ad hoc basis within existing cadastral procedures. Because this information is not registered in a uniform way, insight in all relevant aspects (who has which rights on a certain moment, for what space and for what period(s)) is frequently a problem. The basis of a cadastre is usually a 2D parcel, and the registration has not been set up on a 4D basis. A more integrated approach of the temporal and spatial aspects must be investigated in order to see if improvements can be obtained.

This paper will study the need for a 4D cadastral system by introducing time aspects and cadastre and by describing several case studies, located in different countries (and based on different cadastral systems). Based on these potential requirements, first alternatives for the development of a 4D cadastre are discussed. Some advantages and disadvantages are presented. This paper is a very initial analysis: it does not provide a final solution. A 4D cadastre seams to be very attractive as all other cases (2D with more static parcels, 2D with moving parcels/rights, 3D more static volume parcels) are all fitting into the same total system.

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1. INTRODUCTION

The people-land relationship has a very dynamic nature, which is the motivation for the discussion on 4D cadastre in this paper. People appear and leave (especially in urban area's), people have a limited time to live, governments plan to change environments (spatial planning) or spatial developments can be even completely uncontrolled. Interests of people in land always have an implicit or explicit time component. Examples of rights and restrictions with a temporal element are leases, time-shares, mineral concessions, season bound rights (grazing, picking/collecting vegetation, hunting/fishing, ...) and nomadic passing. Even the right of ownership as known in civil law jurisdictions (*Eigentum, droit de propriété*) has a temporal element related: it is unlimited or indefinite in time (under the existing jurisdiction), but the boundaries of the object can vary in time. A very dynamic example is the case where parcel boundaries follow the movements of natural features such as coastlines or river borders.

Another category of examples that form the motivation for a discussion on 4D cadastre is when a record of history is required on a certain property ("What transfers of ownership occurred between 1900 and 2003"? "What was the location of the parcel boundary in 1980"?) or when history information on land use development in a certain area is needed to support future land policy (think of multipurpose cadastre, land redistribution based on earlier existing people-land relationships, land consolidation, etc). The final category is where a history of the database content is needed to be maintained. E.g. where changes have to be delivered to cadastral data customers for their updates in a certain region (van Oosterom, Maessen, and Quak, 2002).

Land Administration Systems and Cadastres are (or should be) designed to support transactions of real rights of people to land and to provide information to (local) society in relation to this. The registration process itself takes time, especially in a distributed environment, where several organizations have their responsibilities in the transaction process. Place, time and date of agreement, submission to authorities, acceptance by authorities, observation in the field, database update time, etc can be distinguished in relation to this. This means that time may differ with respect to activities in maintenance and update procedures, including adjudication and initial registration.

Land Administration Systems themselves are subject of change because they have to perform in an environment with changing customer demands. This can imply the registration of new object types or of new attributes related to existing objects. It can also imply improved support to the land market, e.g. the introduction of the possibility to have several sequential transactions on the same real estate object at the same day; e.g. person A sells an apartment to person B and person B to person C *at the same day*. On the other side traceability of such transactions can be interesting for other customers

New technologies, e.g. database technologies, data acquisition, Global Navigation Satellite Systems, etc. open new perspectives for implementation of solutions to such demands. Information technology is of strategic importance to be able to deliver Land Administration Systems that can perform in a dynamic environment with a variety of tenures, with changing customer demands.

Standardization is a well-known subject, which started with the establishment of cadastral systems. In both paper based systems and computerized systems standards are required to identify objects, relations between objects and persons (also called subjects in some countries) for accessibility and information supply purposes - also for the purpose of identifying illegal transaction, e.g. in case a seller tries to sell a real estate object to two different persons at the *same day* (which is not an unusual activity in countries without a cadastral system, and even in countries with cadastral systems)

This paper is a fist exploration of the aspects of and requirements for a 4D cadastre. The aim of this paper is to start the international discussion on the requirements for 4D cadastral registrations (if there are any). Temporal aspects are not new and also not unique to cadastral information systems, as they are also recognized and treated within other types of (geographic) information systems. Some general time aspects are presented in Section 2, including a first exploration of its meaning for cadastre. The FIG Core Cadastral Domain Model (CCDM) is explained in Section 3 and does cover both 2D and 3D space and several temporal aspects. Some 4D cadastral cases are presented and analyzed (case 'Dynamic Objects', case 'Time Sharing', case 'Registration of Utilities') in Section 4 and their impact on the CCDM. In this paper the need for an explicit 4D spatio-temporal foundation is discussed (mainly in Section 5). Should a 4D data type be developed in relation to the CCDM or does the existing functionality of the CCDM provide sufficient functionality to manage spatio-temporal aspects of cadastral and land registry systems in general?

2. GENERAL TEMPORAL ASPECTS OF CADASTRE AND LAND REGISTRY

Different aspects of time within GIS have been studied for more than two decades and this work is still going on. One of the more important earlier work in temporal GIS has been done by Langran (1992) and she did also give an overview of the different functions a temporal GIS could support:

- inventory (complete description) - in case of cadastre and land registry this could be an initial registration, which takes a long time in general; so the 'starting point' of a cadastre can be different in one region; this is also valid for an 'end point' e.g. in case of a new regime,
- analysis (explain, exploit, forecast) - in case of cadastre and land registry this is relevant in case of use of cadastral data for spatial planning and land consolidation; for trends analyses (average purchase prices per month/quarter; developments in newly inscribed

mortgages, e.g. average value, interest; indexations on the real estate market over longer time periods - e.g. the Netherlands Cadastre calculated the developments in purchase prices of different categories of houses and apartments since 1993 with index january 1995 = 100); tracing transactions on a certain object over a period of time; forecasting can be required for purposes of planning of human resources - based on trends an expectation of the required human capacity to support the real estate market can be calculated,

- updates (supersede outdated info with new) - in case of cadastre and land registry this is the core business; it can also include the generation and delivery of update files over a certain period to customers in case they like to have a copy of cadastral data for their specific purposes,
- quality control (monitor and evaluate new data, consistent with old data) - in case of cadastre and land registry this can be of importance in many cases, e.g. in case of cadastral map renovation, see Salzman, M. Hoekstra, A. and Schut, T. (1998). Such a renovation means in fact the generation of a complete new version of the cadastral map with impacts on calculated area's. The same is valid in case of re-survey of parcels or in case of analogue to digital conversion of cadastral maps,
- scheduling (identify threshold states, which trigger predefined actions; e.g. buy) - in case of cadastre and land registry there are many examples because of maintenance and update processes to be executed in sequential order,
- display (generate maps or tables of a temporal process) - this could be a land consolidation process in case of cadastre and land registry.

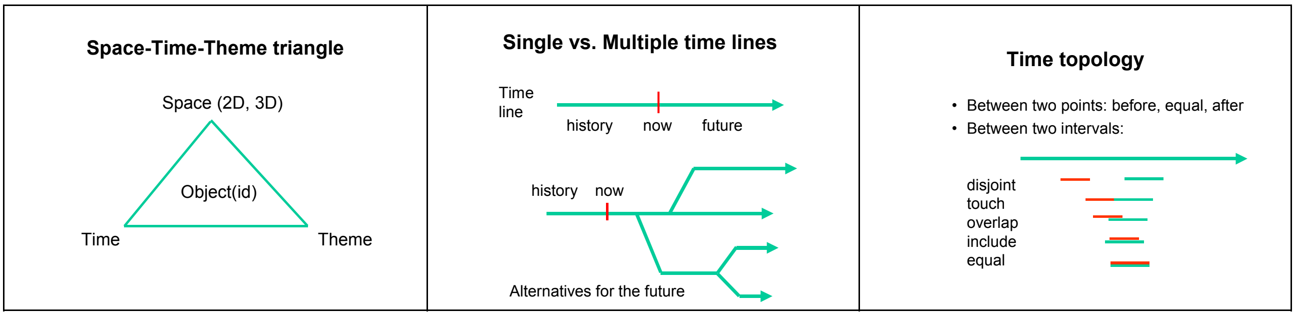

Figure 1: Some temporal principles

Figure 1 shows some of the temporal principles within (G)IS. Any spatio-temporal object has an identity (object id) and thematic attributes as depicted in the space-time-theme triangle (Figure 1 left).

An important concept in temporal modeling is the timeline (Figure 1 middle), where it becomes clear that there is a direction in which the time always marches on. A *time point* or moment in time is defined by a single point on this timeline and there is one very special point and that is ‘now’, which is always changing. A *time interval* is period of time defined by a start and end time on the timeline. The smallest time unit is called ‘*chronos*’ (which can be compared to the resolution or pixel size in a raster GIS). Some patterns of reoccurring events may have to be modeled and the *frequency* indicates how often (fast) this is happening.

The 'unit of time' is 'flexible' in case of cadastre and land registry: sometimes date and place is registerd, sometimes date and time (in case of the register of incoming transactions time could be in minutes, in case of time stamps in a data base time could be in seconds). Here it schould be noted that date depends on type of calendar and time depends on location . In case time sharing of apartments the unit can be one week. Apart from this it is important to know which time is registered: when it happened in the real world (e.g. date of agremeent); when it was observed in reality (date of survey or date of photo); when it was included in the database (time stamps); when it was last checked in reality (in case of map updating); signature/registration/postmark time (related to maintenance and update processes) or display tiem (in case of information delivery to a customer).

Similar to the spatial domain topological relationships may be defined between temporal primitives; Figure 1 (right) shows some possible topological relationships between two time intervals. The figure gives an overview of situations that may appear between two time intervals: disjoint, touch, overlap, include and equal. A 'disjoint' cadastral situation (property situation) may appear if a system is temporal 'out of use' and the reconstructed, based on reconstruction of the past (e.g. land redistribution in ex-communist area's. A 'touch' situation may appear in case of the introduction of a new or renewed tenure system, e.g. the introduction of a new civil code. 'Overlap' appears in e.g. land consolidation procedures; here an 'old' and 'new' parcellation exist temporally in parallel with all its impacts (e.g. a buyer of a parcel of land can be re-allocated at a location which was agreed already with the seller; complex information supply on properties during this period of implementation of the designed re-parcellation in the field), 'include' has a meaning in case of temporal overlapping claims to the same piece of land in case of land conflicts and 'equal' has a meaning in case of equal objection periods for different area's (or 'cadastral office territories' e.g. related to initial registration.

Normally, there is one timeline in history, but possibly many in the future corresponding to alternative scenario's (Figure 1, middle). It is complex to model these multiple future timelines with topology. In principle the multiple timelines could also occurif we want to reconstruct the (partial) unknown past; e.g. in geology there may be different scenario's of the past development. In such a case also the past can have multiple timelines.

When discussing the temporal dimension it is good to distinguish between the different types of time involved. There seem to be three distinct "types" of time in *cadastral databases*:

Type 1, Database Time - examples:

- history of database updates (e.g. for the supply of updates to users of cadastral data who are maintaining their own databases)
- tentative updates (where the database is updated, but the update is not made public to everyone until it is "signed off").

Type 2, Legal Event Time – examples:

- history of ownership
- pre-registration (e.g. a planned subdivision – which might not happen).

Type 3, Variation of the right with time – examples:

- limitation of tenure (e.g. 99 year lease)
- future rights (will take effect in…)
- periodic tenure (e.g. timeshare apartment, seasonal grazing right)
- "Slow and Imperceptible" (property boundary defined by river or sea)
- "moving rights" ("grazing rights" where extent "moves" day by day).

The three types seem to be largely independent – in that the database updates can apply to any type of database entity (including temporal ones). Ownership changes can occur on rights that themselves vary with time, and pre-registration of time varying rights can be required. The types 1 and 2 are more of a recording nature (both real world and system times) and use time stamps in the past. Type 3 is a bit different and mayalso describes time in the future.

3. CCDM: TEMPORAL AND 2D/3D SPATIAL ASPECTS

The foundation of the current CCDM is a 2D and/or 3D parcel with temporal attributes (so, actually the four dimensions are present in the CCDM) with possible fuzzy boundaries (Lemmen and van Oosterom, 2006). This does not mean that every cadastral system should have four-dimensional fuzzy parcels, but the model gives the overall, general framework. The actual systems are in a certain sense 'special cases' of this general model; a number of examples of systems fitting in the CCDM:

- a traditional 2D parcel based system (with exact/accurate boundaries)
- the system extended with 3D VolumeProperties
- a 2D system but with temporal rights, actually the RegisterObjects do have fixed geometry, but the right, restrictions or responsibilities may change over time (could be in according to some kind of repeating pattern).
- a 2D system with well defined parcels, but extended (in certain areas) with more fuzzy types of parcels (SpaghettiParcels, PointParcels, TextParcels)

There are two different approaches when modeling the result of dynamic systems (discrete changes in the state of the system), these are event and/or state based modeling:

- in event based modeling, transactions are modeled as a separate entity within the system (with their own identity and set of attributes). When the start state is known and all events are known it is possible to reconstruct every state in the past via traversing the whole chain of events. It is also possible to represent the current state, and not to keep the start state (and go back in time via the 'reversal' of events).
- in state based modeling, only the states (that is the results) are modeled explicitly: every object gets (at least) two dates/times, which indicates the time interval during

which this object is valid. Via the comparison of two succeeding states it is possible to reconstruct what happened as a result of one specific event. It is very easy to obtain the state at a given moment in time, by just selecting the object based on their time interval (tmin-tmax).

The CCDM (see Figure 2) is based on a merger of these two temporal modeling approaches. The SourceDocument objects (Legal and Survey) can be considered as the explicit representation of the events due to which the other objects are changed. This is reflected in the typical state based modeling attributes tmin-tmax of objects such as RegisterObject, Person and RRR (and their specializations). Specific additional (legal) temporal aspects of RRR are generalized to a TimeSpec attribute. This attribute is capable of handling also other temporal representation such as reoccurring pattern (every week-end, every summer, etc.) Note that the Right, Restriction and Responsibility objects all inherit the TimeSpec attribute.

Further near all objects inherit the tmin-tmax temporal attributes via either RegisterObject, RRR or Person. It would have been possible to introduce a new object (TemporalObject with a TimeSpec attribute) from which in turn the mentioned classes would inherit their temporal attribute (mainly because of legitability this was not done). In addition to the event and state modeling, it is also possible that the 'parent/child' associations between the Immovables (RegisterObject) are modeled (lineage); e.g. when a cadastral parcel is subdivided. However, as these associations can also be derived from a spatio-temporal overlay, it was decided to not further complicate the model with the explicit parent-child relationships. In case of Person and RRR it does not seam useful or meaningful to maintain lineage at all.

Parcels have a 2D or 3D geometric description. A Parcel corresponds one-to-one to the tp_face (or tp_volume in 3D) in a topological structure (as defined by ISO TC 211 and OGC). Time is not (yet) integrated in the data types of the topology/geometry. It is currently treated as a separate attribute (tmin/tmax everywhere and timeSpec in RRR). One could image really full spatio-temporal RegisterObject representations for the definition of moving object with RRRs attached; e.g. to define grazing rights moving/changing-location over seasons (2D and time) or a Marine cadastre with moving/changing fishing rights in the ocean (3D and time).

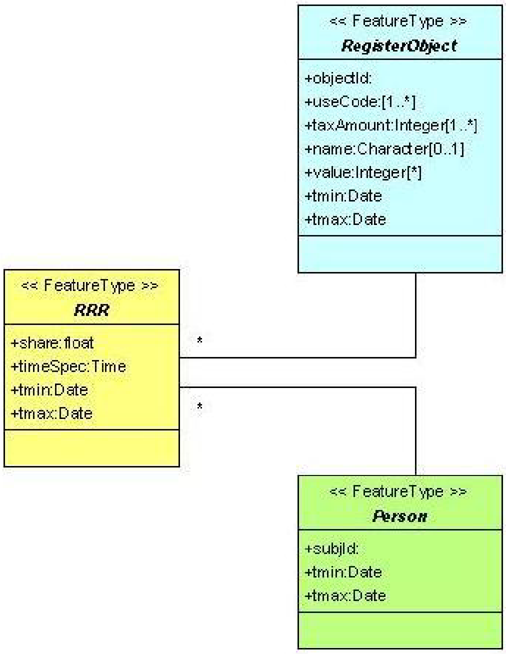

Figure 2: Core of the CCDM: Person, RRR (Right, Restriction, Responsibility) and RegisterObject

The complex of 2D or 3D (ISO/OGC) topology structures are valid at every moment in time. There are never gaps or overlaps in the partition. However, to edges belonging to different time spans (defined by tmin-tmax) may cross without a node. The temporal topology must also be maintained: that is no time gaps or overlaps in the representations. Therefore the structure is based on spatio-temporal topology.

4. 4D CADASTRE CASES

This section explores the need for a 4D registration by analyzing the temporal aspects of three time related cases from practice: case 'Dynamic Objects' (subsection 4.1), case 'Time Sharing' (subsection 4.2), and case 'Registration of Utilities' (subsection 4.3)

4.1 Dynamic objects

4.1.1 Moving boundaries - e.g. in case of river meandering

Parcel boundaries in the field can 'move' over time because of human activities as plough a field, place a new fences or because of natural phenomena e.g. river meandering, etc. Adverse possession (which has a time component) can be related to this. This is based on the rules of limitation: the claim of the landowner against a squatter shall become time barred after a certain period. This means that the squatter can no longer be evicted from the property. But in general its effect will also be positive.
The physical occupant gets title by his possession of the land. Adverse possession has also a wider application. In cases of informal transactions, such as two farmers who swap land, but

don’t register the change, adverse possession fulfils legally a useful function because it ascertains the ownership situation. The requirements to obtain title vary per jurisdiction. The time needed can be 12 years, 20 years or even more.

There seems to be some similarity here with the 'geospatial lifeline models' as introduced by Egenhofer (2006). A geospatial lifeline models continuous movement through geographic space as a time-stamped record of locations that an object has occupied over a period of time, enabling such analyses as alibi testing by evaluating whether two individuals could have met. Lifelines are embedded in an abstract three-dimensional space that is comprised of the two-dimensional plane and an orthogonal, directed time axis. Typically the gaps between recorded space-time samples are filled by using suitable interpolation techniques, revealing one likely path the object may have taken. A complementary semantics of the gaps is described through the set of all possible space-time points that the object may have occupied between the space-time samples. Based on heuristics about an object's maximum travel speed, a lifeline bead captures for the object all possible space-time points between two consecutive space-time observations. A bead is modeled as the intersection of two half-cones pointing in opposite directions. One from the origin pointing in the direction of the time axis, and one from the destination pointing in opposite direction. (Egenhofer 2006).

The natural boundary of the parcel is exactly defined by the real-world object (e.g. high tide mark) at any point in time, but only fixed by measurement at discrete moments (when a survey is done). Between surveys, as far as the database is concerned, the natural boundary falls within some “bead” (actually a drawn-out bead).

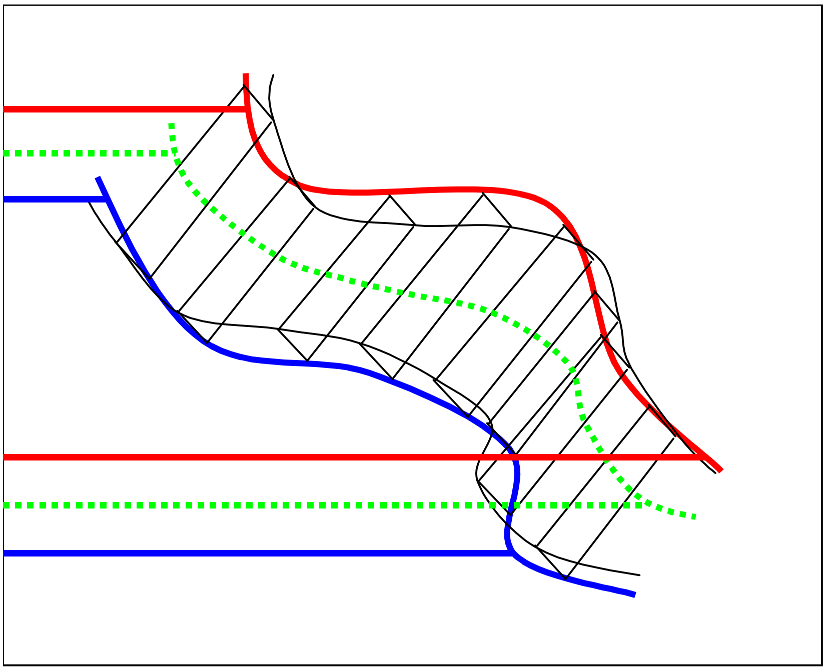

Figure 3 “Time bead” of a natural boundary

In figure 3 the parcel is surveyed at time 1 (blue) and time 2 (red). The actual boundary (unknown) falls somewhere in the time bead at any point of time between 1 and 2.

4.1.2 Case Moving Grazing Cattle

Experience reveals that some countries develop land legislation, which endeavors to integrate customary tenure within the formal system (Augustinus et al, 2006). The recognition of customary rights also devotes attention to rights of sheep and cattle farmers. In many countries there are serious conflicts between traditional nomadic sheep or cattle farmers and arable farmers about grazing and farming lands (such as Kenya, Tanzania, Rwanda).

Nomadic sheep and cattle farmers bring their animals since very long time from one area to another looking for food which is available at known places depending on the season. Today they ’cross’ lands of arable farmers, arable farmers place fences around their lands. To avoid conflicts fences should be 'open', e.g. two times a year.

This implies that Immovables in the Core Cadastral Domain Model (see Lemmen and van Oosterom, 2006) have a dynamic aspect, that is, time is involved. Therefore, the most fundamental unit of the cadastral model could be a *3D spatio-temporal parcel (actually four dimensions) with possible fuzzy boundaries* (see van Oosterom et al, 2004). This can then be used to represent dynamic/ temporal situations.

The case of those 3D spatio-temporal parcels provide sufficient functionality; Moving Grazing cattle does not require a 4D data type. It should be noted that an alternative option in registration is the registration of a restriction to the 'arable' parcel describing the rights of the pastoralists.

4.2 Case Time Sharing

A title to a timeshare is just like any other title. It can be traded, mortgaged, etc. The time range is not actually specified in the title. For example, if a unit in a building is to be timeshared on a weekly basis, it could be described on 52 titles, each being for a 1/52nd share in the unit. The agreement as to which week is not part of the information recorded on the title.

For a building with (say) 40 units, to be time-shared on a weekly basis, there might be titles issued for 40*52 shares, each being interpreted as one unit for one week each year (and implying a periodic cycle of one year). The titleholders enter into an agreement with a management company as to how the share is to be managed and let. For example, which week of the year the titleholder is entitled to.

In Queensland, Australia, timeshare schemes are becoming less popular recently. One issue is that the shares are of relatively small value (in real-estate terms), and may be overlooked or forgotten by the owners. This is not a problem for the registering authority, but can be for the body corporate – who needs to levy charges for maintenance. Since the time component is not registered in the title, and therefore not available to the registering authority, it is currently inappropriate for it to be recorded in the Cadastre (and therefore the cadastral database). However, in the future the real estate rights, including, timeshares would benefit from improved regulations and registration (and thereby serving the real estate legal security).

Another temporal aspect as can be found within the Cadastre of Queensland is formed by the so called 'Slow and Imperceptible' parcels: The definition of the property is based on a boundary that changes slowly, imperceptibly, with no artificial intervention (such as construction work). As a result, the shape of the land parcel will have changed over time. A historic database is needed to represent this movement.

The current Cadastre of Queensland is capable of handling timeshares and the 'Slow and Imperceptible' parcels.Some background information on the Queensland Titling System helps to understand how the temporal (and 3D) aspectsfit in the current registration. The Torrens titling system has proved to be very flexible, and has provided the necessary infrastructure to administer significantly varied requirements in relation to land ownership and rights. Thus there was no legislative change needed to include timeshare titles. In effect, if the right can be defined unambiguously, it can be included in a title. The following types of parcels are recognized:

- flat survey (2D region)
- volumetric Survey (with actual bounds described in space)
- building Format (with bounds defined by walls etc.)
- strata (to the depth/height of – effectively 2D parcels horizontally sliced into strata)[1].

Land Title Act 1994:

- 48B Standard format plan: A standard format plan of survey defines land using a horizontal plane and references to marks on the ground. Example of marks—posts in the ground
- 48C Building format plan:
- A building format plan of survey defines land using the structural elements of a building, including, for example, floors, walls and ceilings.
- For subsection (1)— structural elements, of a building, includes projections of, and references to, structural elements of the building.
- Example for subsection (2)— Projections might be used to define a lot that includes a balcony, courtyard, roof garden or other area not bounded, or completely bounded, by a floor, walls and a ceiling.
- 48D Volumetric format plan: A volumetric format plan of survey defines land using 3 dimensionally located points to identify the position, shape and dimensions of each bounding surface.

[1] Strata title are not used anymore, but they still do exit in the database (historic reasons). In case of 3D registrations nowdays either a Volemetic Survey of Building Format is used.

Figure 4 shows two parts of a Volumetric survey plan of a complex at the Gold Coast as registered by the Cadastre in Queensland. The complex 3D nature of the different apartments units becomes clear. In addition to the 3D spatial aspect also timeshares are used relatively often at the Gold Coast, which makes this a true 4D cadastral registration case.

It should be noted that the CCDM provides sufficient functionality to describe this case, there is no need for an explicit 4D data type or system.

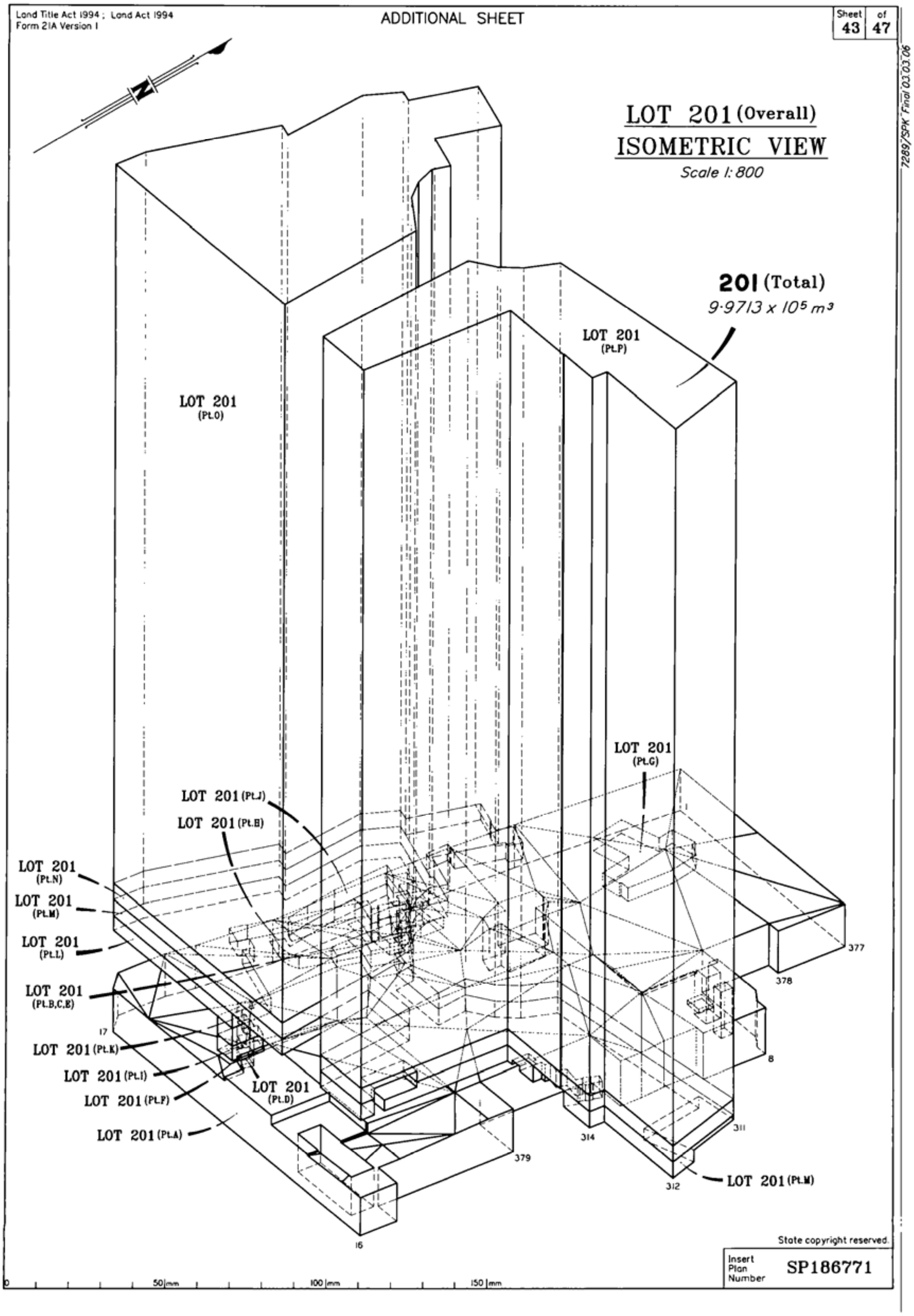

Figure 4-1: part 43 of Volumetric survey plan of a Gold Coast apartment complex

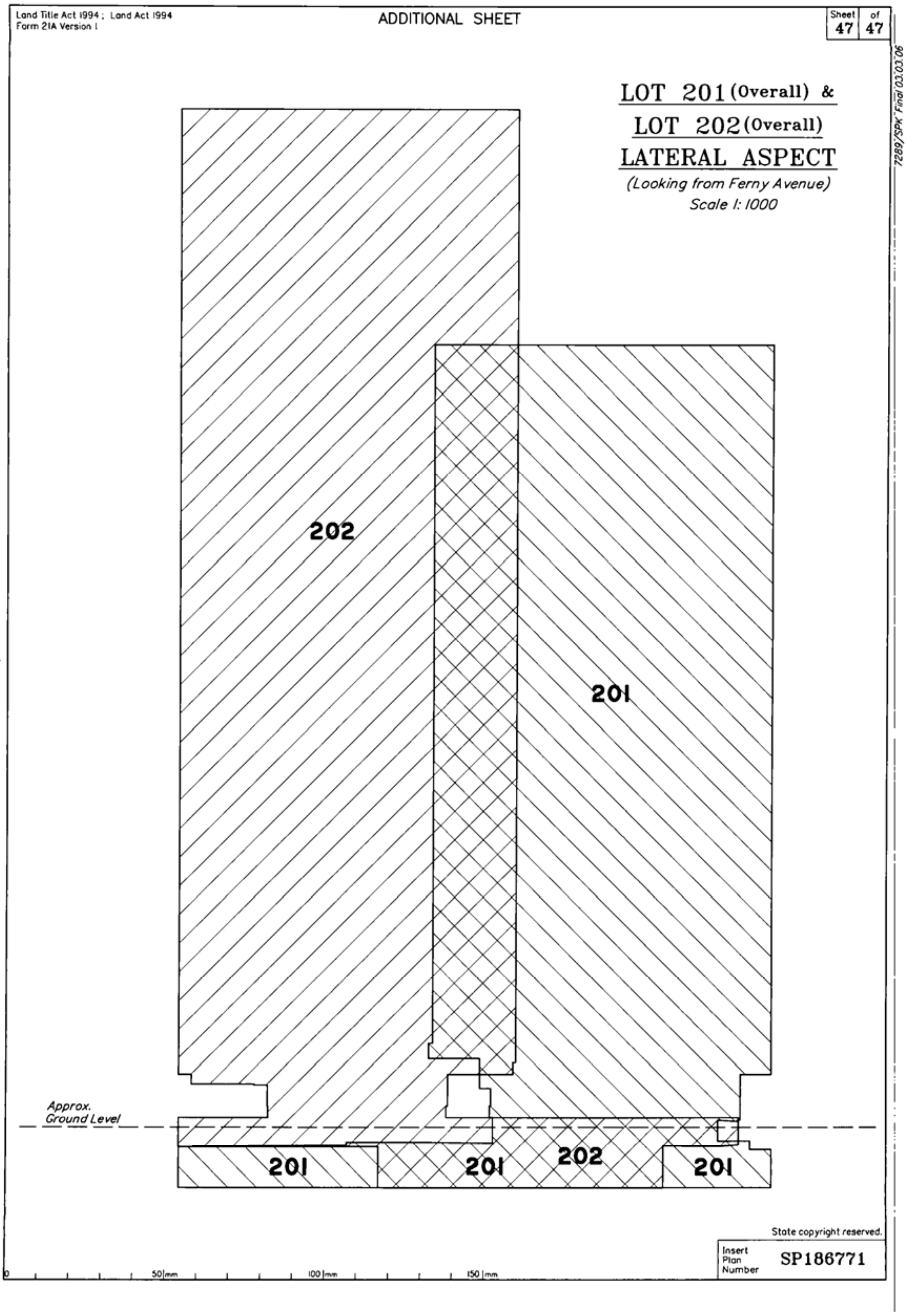

Figure 4-2: part 47 of Volumetric survey plan of a Gold Coast apartment complex

4.3 Case Registration of Utilities

This case is from The Netherlands; it describes registration of utilities and other cables and pipelines. Utilities for water, gas, power, telecommunication, but also industrial pipelines are a very important and comprehensive part of the subsurface infrastructure in the Netherlands. For the Netherlands, a country of 41,000 km^{2}, the total length of the subsurface infrastructure is estimated as nearly two million km, and a value of about 100,000,000 Euro. (Ploeger and Stoter 2004).

The legal status of those cables and pipelines was unclear for a long time. Are they fixtures or chattel? In 2003, in the case of cables for telecommunication the Dutch Supreme Court judged that those underground networks are immovable (*Hoge Raad* of the Netherlands, 6 June 2003). After that judgment it is has generally been accepted that all (underground) networks must be considered to be fixtures. Because utility networks are immovable, and as such 'registered property' under the Duch Civil Code, a registered notarial deed is required for the transfer of ownership and the establishment of limited real rights (like usufruct or mortgage). The same applies for other networks. However at this moment the ownership of those networks is not clear due to the rule of *superficies solo cedit* (vertical accession). This rule implies that the person who owns the land is also owner of all immovable things above and below the land. Only in the case of telecommunication cables, the Telecommunication Act states that the rule *superficies solo cedit* doesn't apply on them. To solve this legal uncertainty it is expected that the Dutch Civil Code will be changed. In short this change means that any network to the transport of fluids, electricity of gas is owned by the competent constructor. "Competent" implies that the constructor must have a right to put the network in the land; or he is the landowner himself or got the permission to build the network (e.g. by contract or because of a real right like a lease of easement).

At this moment the Cadastre Act doesn't give any rules how to deal with the cadastral registration. A procedure has been developed by the Netherlands' Kadaster shortly after the Supreme Court decision. In case of a transfer related to a telecom-network, the holder of a telecom-network offers the spatial description in 2D (centre line) of the network to the cadastre for making a 'network map'. Both deed and network map are registered in the Public Registers. The deed of transfer only refers to one or just a selection of parcels, the so called 'anchor parcel(s)' (Ploeger and Stoter 2004). On all other intersecting parcels an object restriction (legal notification) is registered, code 'TC' or 'TCD' in the Land Registry Information System AKR. Because these intersecting parcels are not mentioned in the deed, they can only be indicated by a spatial query. The spatial description of the network can be incorporated in the Cadastral Geographical Data Set (as telecom-networks).

In near future a more general procedure will be introduced by a change of the Cadastre Act, based on the provisional procedure described. A notarial deed is needed to register the ownership of any (subsurface) network. The same applies for the transfer of the ownership. In the deed of registration the notary has to state who is the owner of the network. For this conclusion he will refer to (historical) information about the construction of the network, the competence of the constructor (summing up the rights per land parcel), and transfers in the past. Like in the actual procedure for the transfer of telecommunication network the notarial deed will also refer to a network map, based on information supplied by the manager of the network, a map that will be registered in the public registers. New is the fact that the network will get an own cadastral identifier, making it a true 'first class' cadastral registration object. The networks have an important 3D aspect: the height below (or above) the surface. These heights should be given relative to the surface, but also in an absolute height reference system. There is also a 4D aspect: networks change in time: they are renewed, extended or shortened. This means that after such a change in the network the registration in Cadastre and Public Registers (the registered network map) doesn't reflect the actual construction. However, in the proposed new legislation it seems that legally the actual (change in) the construction of the network is decisive for the extent of the ownership.

For the registration of changes in the network in time, it is good to consider the different network segments (and do not only treat it as a whole), which can be updated. A recent report for the Netherlands (Penniga, van Oosterom, 2006) contains a more detail analysis and suggestions for possible future sustainable registrations.

Figure 5 taken from (Penniga, van Oosterom, 2006) presents a conceptual model for registration of cables and pipelines represented in Unified Modeling Language, UML. The class 'LegalNetwork' is a specialization of the class OtherRegisterObject in the FIG Core Cadastral Domain Model Version 1.0 – CCDM 1.0 (Lemmen, van Oosterom, 2006). Apart from LegalNetwork a class PhysicalNetwork is distinguished. The LegalNetwork contains attributes networkType (gas, water, electricity, etc.), status (planned, in use, not in use), geometricQuality (indicates the accuracy of co-ordinates in x, y and z direction), dangerous (Boolean indicating if there is danger) and belowSurface (boolean indicating if the LegalNetwork is under or above surface). The object LegalNetwork has a method getGeometry(), this method determines the geometry based on LegalBuffer and the associated PhysicalNetwork. It is very well possible that registration will be organized in a distributed environment: LegalNetwork at Cadastre and PhysicalNetwork at the registration of the network holder (owner). This is represented in Figure 5 as a the area 'Outside Cadastre' around PhysicalNetwork and classes NetworkNodes and NetworkSegments. The relation between both LegalNetwork and PhysicalNetwork types of is that geometry of the LegalNetwork can be derived from PhysicalNetwork by buffering (shape and extension). It has to be noted that in such a distributed environment the network holder (owner) has to keep historical versions of the network (in order to keep references from LegalNetwork consistent). In case of updates (changes) of the PhysicalNetwork a signal has to be sent to Cadastre, which must then decide to move (or not) from the existing version of LegalNetwork to the new version. In this scenario id's and timestamps are of crucial importance. In case of a situation where distributed processing (registration) is not yet possible it may be an option to store a copy of the PhysicalNetwork at Cadastre. This can be compared with the registration of natural persons at Cadastre, as a copy from Municipal Personal Records Database - Population Register, as long this Population Database is not yet available as an authentic (key) register, see also (Groothedde 2006). Finally it can be noted that the PhysicalNetwork will be managed as a set of segments without explicit storage of nodes.

Again it can be concluded that there is no need for a specific data type in the CCDM.

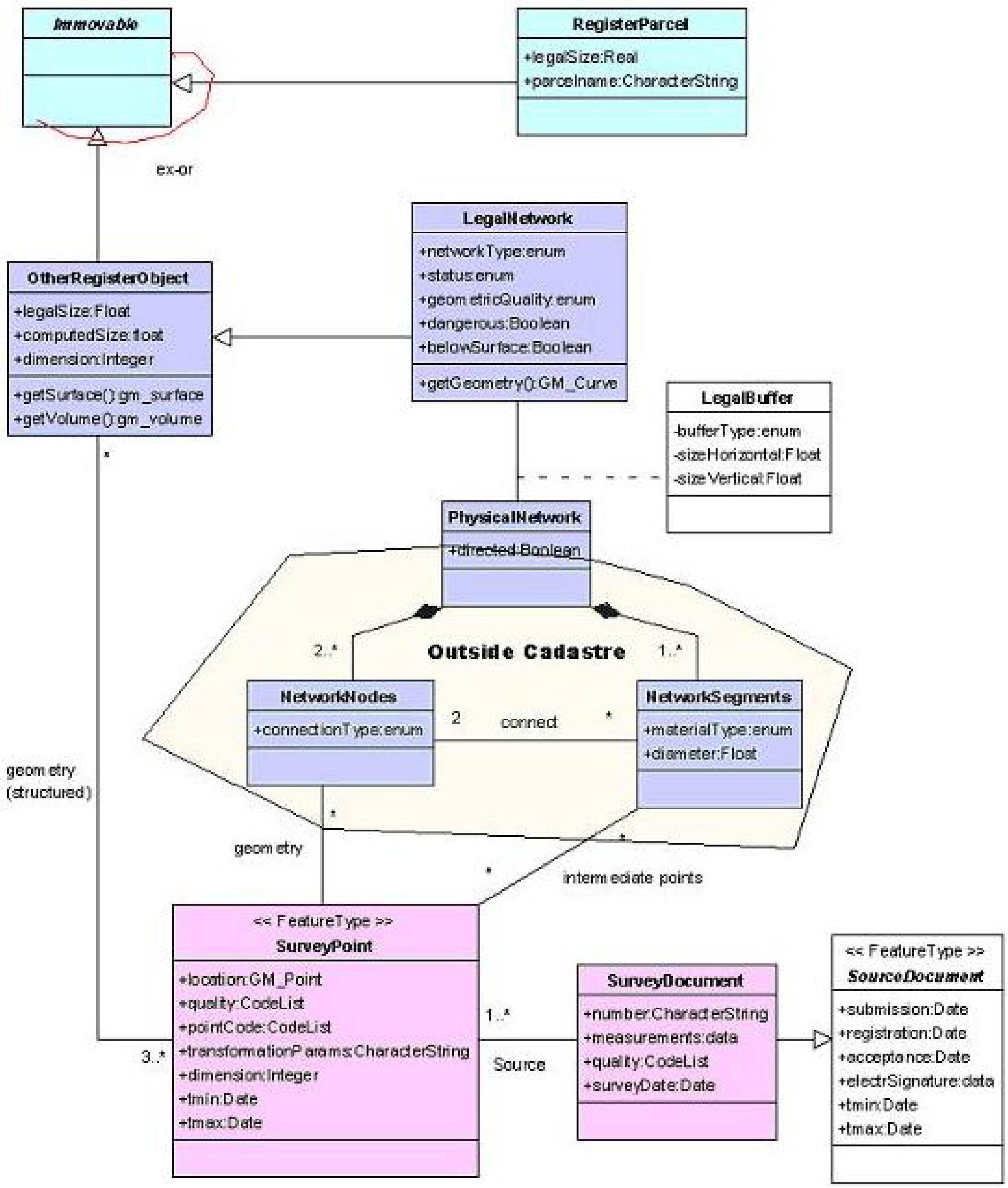

Figure 5: Conceptual model for registration of cables and pipelines

5. DISCUSSION AND CONCLUSION

The relationship between people and land is very dynamic. From a legal perspective it is clear that interests in land have a component in time. The presented cases in this paper have shown requirements for a 4D cadastre as this reflects the actual real world situations. On the other hand it is also concluded in this paper that most of the cases can be represented with separate spatial and temporal attributes. However, deep integrated treatment of space and time in one internal 4D data type representation might have some benefits for the future realization of a 4D cadastre. Some of the potential benefits are:

1. optimal efficient 4D searching (specifying both space and time in same query) can only be realized if a 4D data type (and index/clustering) is used, otherwise the DBMS (query plan) has to select first on space and then on time (or the reverse order). Note that even 2D index/cluster is most likely sufficient for reasonable performance as the 3rd dimension and time are less selective. So, this is not a real strong argument for moving to 4D data types,
2. with true 4D data types parent-child relationships between parcels (the lineage) are neighbor queries in a topological structure (neighbors for which at least the time attribute did change), which is more efficient than a spatio-temporal overlay needed as in the non-integrated approach; see Figure 6 (left): Parcel P3 has parent parcel P1 and children parcels P4 and P5,
3. 4D analysis: 'Overlap' appears in e.g. land consolidation procedures; here an 'old' and 'new' parcellations exist temporally in parallel with all its impacts. Another example is the question: do two moving cattle rights have spatio-temporal overlap/touch (Figure 6 right)? If stored and represented in the database by a 4D data type, this is just a simple query. If stored as separated attributes, this is not a trivial query to answer,
4. but most important if we do want the full (4D) partition (of 3D space+time, no overlaps, no gaps) as our foundation for a 4D Cadastre, having true 4D geometry and topology (space and time integrated) is the most solid foundation.

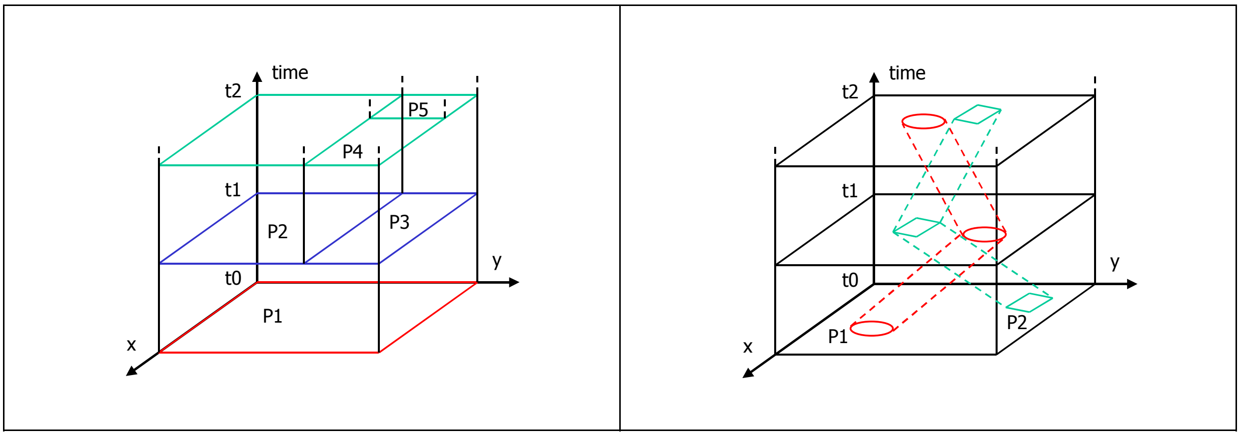

Figure 6: Integrated treatment of space (2D) and time: left the subdivision of parcels and right the representation of moving cattle

However, there are also a number of arguments, which can be made in favor of separate treatment of space and time:

1. the separate 3D + time attribute model of the CCDM is able to represent all 4D Cadastre cases presented in this paper,
2. current (new, but state of the art) technology can be used to implement the separated approach while for support for true 4D geometry and topology further R&D activities will be required,
3. needed flexibility in temporal modeling: just adding one simple time dimension might not be sufficient to represent complex temporal situations and therefore the integrated 4D model alone will not be sufficient.

For the medium to long-term future, it seams that if the solid foundation of a spatial-temporal partition as Cadastral foundation becomes more important, 4D data types (geometry/topology) should be considered. Further the true 4D basis might be the cheapest solution in the long run as no special cases need to be treated in another way anymore (because everything would fit into this model). However we should be realistic by stating that it is unclear if the true 4D data type is the way forward in practice in the short to medium term future. This also depends on less technical considerations such as the importance of the 4D space-time partition in relation to other cadastral aspects. More investigations are needed here in relation to all aspects of the cadastre: legal, organizational and technical.

It should be noted that these conclusions are made from a technical and academical perspective. The time component is not new in cadastral registrations. In fact it is relevant for many (if not all) activities of cadastral organisations (in keeping their registration of rights, restrictions and responsibilities up to date) and for support of cadastral organisations to land markets, land taxation, mortgage industry, spatial planning, tenure security, etc. In that sense cadastres already deal with the temporal aspect within their current systems. However the question is if those systems are capable of handling all temporal aspects and requirements. Problems appear in case cadastral systems do not exist or perform badly.

The time aspects in all their appearance disserves further attention when it deals about system development, development of standards and thus contributing to performance improvement of land administration and cadastral organisations.

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REFERENCES

Augustinus, C, Lemmen, C.H.J, Oosterom, van, P.J.M., 2006, 'Social Tenure Domain Model - Requirements from the Perspective of Pro-Poor Land Management', 5th FIG Regional Conference - Promoting Land Administration and Good Governance, Accra, Ghana, March 8-11, 2006

Egenhofer, M.J. (2006), GeoSpatial Lifelines, in: Spatial Data: mining, processing and communicating, Abstracts Collection Dagstuhl Seminar, eds: Jörg-Rüdiger Sack, Monika Sester, Michael Worboys3 and Peter van Oosterom

Groothedde, A., 2006 'ICT Trends and Institutional Change - with a special attention to the Land Administration Sector', XXIII FIG Congress, 'Shaping the Change' Munich, Germany, October 8-13, 2006

ISO TC 211/WG 2, 1999a, 'Geographic information - Spatial schema', Technical Report second draft of ISO 19107 (15046-7), International Organization for Standardization, November 1999.

Langran, G., 1992, Time in Geographic Information Systems (London: Taylor & Francis).

Lemmen, C.H.J. and Oosterom van, P.J.M., 2006, 'Version 1.0 of the Core Cadastral Domain Model', XXIII FIG Congress, 'Shaping the Change' Munich, Germany, October 8-13, 2006

Oosterom, van P.J.M. and Lemmen C.H.J., 2001, 'Spatial Data Management on a very large cadastral database', in: 'Computers, Environment and Urban Systems', Theme Issue 'Cadastral Systems', p. 509-528, Volume 25, number 4-5, 2001, Elsevier Science, New York.

Oosterom, van, P.J.M., C.H.J. Lemmen, T. Ingvarsson, P. van der Molen, H. Ploeger, W. Quak, J. Stoter, and J. Zevenbergen (2006). The core cadastral domain model. Accepted and to be published in: Computers, Environment and Urban Systems, Volume 30, 5.

Oosterom, van, P.J.M., C.H.J. Lemmen and P. van der Molen, 2004: 'Remarks and Observations related to the further development of the Core Cadastral Domain Model', in: Proceedings of the Workshop Standardisation in the Cadastral Domain, Bamberg, Germany, 9-10 December 2004, FIG, Denmark, 2004

Oosterom, van, P.J.M., B. Maessen, and W. Quak (2002). Generic query tool for spatio-temporal data, In: International Journal of Geographical Information Science, Volume 16, 8, pp. 713-748

Penninga, F. and P.J.M. van Oosterom (2006). Kabel- en leidingnetwerken in de kadastrale registratie (in Dutch). http://www.gdmc.nl/publications/reports/GISt42.pdf, GISt Report No. 42, Delft, Mei 2006, 38 p.

Ploeger, H.D. and J.E. Stoter, 2004, Cadastral Registration of Cross-Boundary Infrastructure Objects, FIG Working week 2004, May, Athens, Greece.

Salzman, M. Hoekstra, A. and Schut, T. (1998), Cadastral map renovation: a Dutch perspective, XXI International Congress : developing the profession in a developing world : Commission 7 : cadastre and land management / International Federation of Surveyors. - Brighton : FIG, 1998 ; p. 672-682

Stoter, J.E., 2004, 3D cadastre, PhD thesis, 327 pp, TU Delft, the Netherlands

Stoter, J.E. and Oosterom, van P.J.M. (2006). 3D Cadastre in an International context: Legal, Organizational, and Technological Aspects, Taylor&Francis (CRC Press), Boca Raton FL USA, New York USA, Oxon UK, ISBN 0-8493-3932-4.

BIOGRAPHICAL NOTES

Peter van Oosterom obtained a MSc in Technical Computer Science in 1985 from Delft University of Technology, The Netherlands. In 1990 he received a PhD from Leiden University for this thesis "Reactive Data Structures for GIS". 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. Since 2000, he is professor at the Delft University of Technology (OTB) and head of the section 'GIS Technology'. His main research interests are geo-DBMS, generalization, 3D and temporal GIS, distributed geo-information handling, and cadastral applications. He is European editor for the International Journal on Computers, Environment and Urban Systems CEUS.

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). 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 Geoinformation and Land management. He is also chairman of the FIG working group on 3DCadastres.

Jantien Stoter 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, Department of Geodesy, 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. Scince April, 2004 she changed position and moved to ITC, Enschede where she is now associate professor, focusing on 'multirepresentations at different scales'.

Rod Thomposon holds Graduate Diploma of Computer Science at University of Queensland, and Master of Engineering Science (research) at the University of Queensland (and is currently working a PhD Delft University of Technology: "Towards a Rigorous Logic for Spatial Data Representation"). After several other jobs in industry and government, he moved in 1985 to the Queensland Department of Natural Resources and Mines, where among others he designed and led the implementation of the Digital Cadastral Data Base (the DCDB). This was one of the first systems worldwide to implement a truly corporate spatial database, based on the relational model. He has been a member of the Intergovernmental Committee on Surveying and Mapping (ICSM) working group on Topological Data, which produced the

Harmonised Data Model for spatial data interchange within Australia. He is currently Senior Technical Advisor at the Department of Natural Resources and Mines (NRM), Queensland Government, Australia.

Christiaan Lemmen holds a degree in geodesy of the University of Delft, The Netherlands. He is an assistant professor at the International Institute of Geo-Information Science and Earth Observation ITC and an international consultant at Kadaster International, the International Department of the Netherlands Cadastre, Land Registry and Mapping Agency. He is vice chair administration of FIG Commission 7, 'Cadastre and Land Mangement', contributing editor of GIM International and guest editor on Cadastral Systems for the International Journal on Computers, Environment and Urban Systems CEUS. He is secretary of the FIG International Bureau of Land Records and Cadastre OICRF.

CONTACTS

Peter van Oosterom
Section GIS-technology, OTB Research Institute
Delft University of Technology
P.O. Box 5030
2600 GA Delft
THE NETHERLANDS
Tel. +31 15 2786950
Fax +31 15 2782745
E-mail:oosterom@otb.tudelft.nl
website http://www.gdmc.nl

Hendrik D. Ploeger
Section Geo-Information and Land management, OTB Research Institute
Delft University of Technology
P.O. Box 5030
2600 GA Delft
THE NETHERLANDS
Tel.: + 31 15 2782557
Fax: + 31 15 2782745
Email: h.ploeger@otb.tudelft.nl
Website: www.juritecture.net

Jantien E. Stoter
International Institute or Geo-Information Science and Earth Observation
P.O. Box 6
7500 AA Enschede
THE NETHERLANDS
Tel. +31534874444
Fax +31534874400
E-mail: stoter@itc.nl

Web site: www.itc.nl

Rod Thompson
Queensland Government, Department of Natural Resources and Mines
Landcentre,
Main and Vulture Streets,
Woollongabba
Queensland 4151
AUSTRALIA
E-mail: Rod.Thompson@nrm.qld.gov.au

Christiaan Lemmen (for ITC address see Stoter)
Cadastre, Land Registry and Mapping Agency
P.O. Box 9046
7300 GH Apeldoorn
THE NETHERLANDS
Tel.+31.55.5285695
Fax +31.55.3557362
E-mail : lemmen@itc.nl
Web site: www.kadaster.nl