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4D cadastres: First analysis of legal, organizational, and technical impact—With a case study on utility networks

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ABSTRACT

The increasing complexity and flexibility of modern land use requires that cadastres need an improved capacity to manage the third dimension. As the world is per definition not static, there also will be needs in relation to the representation of the temporal (fourth) dimension either integrated with the spatial dimensions or as separate attribute(s). In this paper, registration of utility networks in cadastre are considered in this 3D + time (=4D) context. A number of countries in the world have developed methods to register utility networks complying with their legal, organizational, and technical structure. We researched the different approaches of three specific countries: Turkey, The Netherlands and Queensland, Australia. These are analysed to evaluate a solution that matches legal, organizational, and technical cadastral requirements in the most optimal way.

Introduction

The use of land is always related to a certain amount of (3D) space and spans a certain amount of time (3D + time, or 4D). The latter is well illustrated by leasehold and time-shares. However, traditionally cadastres are based on a representation of the division of land in 2D on a certain moment in time, obscuring the 3D and 4D aspects of land ownership in cadastral registers and maps (UN and FIG, 1999; Van der Molen, 2003; Stoter, 2004; Van Oosterom et al., 2006). Because of growing pressure on land, and rising land values, leading to more intensive and complex land use, we argue that there will be a growing need for 4D (including 3D) information in cadastral registers. Most cadastral data models are still based on 2D cadastral parcels. This has proved to be not suitable in all cases for organizing and modelling the information of complex commodities and interests in land (Kalantari et al., 2008; Bennett et al., 2008).

This observation is especially true for underground utilities. Insufficient and unclear information about location and depth of underground utilities is a major cause of damage to the utilities during excavation operations. The impact of this damage cannot be overestimated as this has been causing various problems and even resulted in tragic accidents. For example, the economic loss of the damage to gas pipelines in Bursa, Turkey was two hundred thousand US dollars in 2005 (Karatas, 2007). In Istanbul, with a population over 15 million, some accidents have occurred during excavation operations which resulted in damage to telecommunication networks and to a subway line, causing a significant direct and indirect economic loss (Doner et al., 2008). In China it has been estimated an economic loss of up to two hundred million US dollars per year during eighties and the beginning of nineties (Du et al., 2006). In the Netherlands, 40,000 damage reports to infrastructures are reported on a yearly basis causing about €40 million direct loss and €80 indirect loss million per year. Statistics in other countries (e.g. Roberts et al., 2002) reveals similar striking figures. Apart from the economic losses, damage inflicted to utilities even resulted in tragic accidents, such as the Ghislenghien disaster on 30 July 2004; the explosion of a high pressure gas pipeline in Belgium that killed 24 and injured 123 persons.

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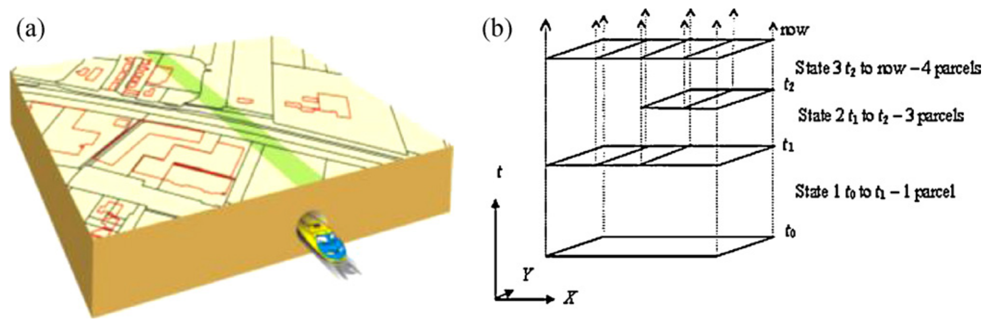

Fig. 1. (a) Illustration of 3D (railway tunnel crosses several land parcels) and (b) temporal concept (changes of state of a subdivision) in cadastral register.

Although the actual needs for 4D cadastre in relation to the costs should also be understood through market analysis, this paper explores the technical, organizational and legal implications of 3D and 4D cadastres. The representation of the third dimension has proved to be especially relevant for apartment units and for physical objects that cross above or below land parcels, such as tunnels (Fig. 1a), underground shopping malls and utility networks. In addition the time dimension is required to be able to record how the legal status of land is changing in time. In most cadastral registers, the time dimension is represented by a versioning of the objects (the state-based model) represented by time stamps that indicate the creation and deletion of represented objects in the cadastral system, see Fig. 1b (Van Oosterom, 1997).

Methodology

Establishing a 4D cadastre, which registers and provides access to all required 4D information of real estate, is not simple, since it comprises legal, organizational as well as technical issues. The aim of this research is to show how these three issues interact. First, the conceptual basis of a 4D cadastre has been studied based on the ISO Land Administration Domain Model (LADM, ISO/TC211, 2009) for utility networks to explain the specifics of physical and legal representations. Secondly, an empirical case study was carried out in three countries that are moving towards a 4D cadastre with different approaches fitting within their legal, organizational, and technical frameworks: in Turkey, in which the land parcel based system has been largely unchanged until now; in the Netherlands,

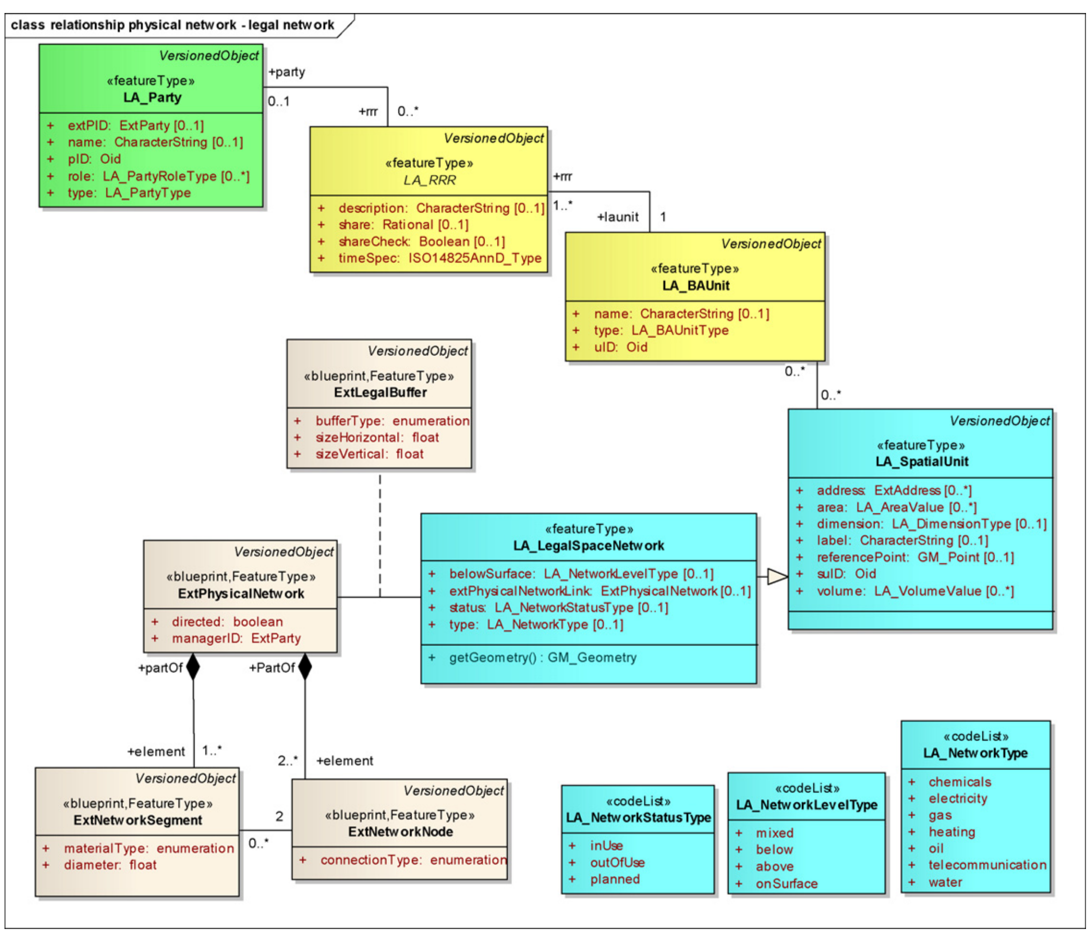

Fig. 2. The conceptual model for representing utility network (physical and legal network).

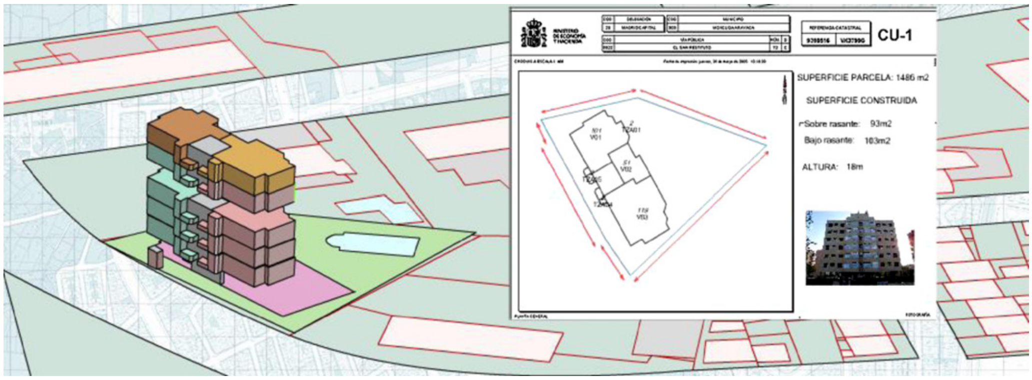

Fig. 3. 3D impression of individual units with floor sketch, photography and relevant attributes (courtesy to the Spanish cadastre).

which changed recently the Civil Code and the Cadastre Act in order to consider utility networks as distinct type of real estate objects; and in Queensland, where it is possible to establish 3D parcels or restrictions with their own 3D geometry. The conceptual basis that we propose for 4D cadastre is presented in "Conceptual basis for 4D cadastre" section. "Cadastral registration of utilities in three countries" section presents the results of the case studies in the three countries and "Results and discussion" section concludes on the requirement analysis phase by specifically focusing on how the conceptual basis relates to current practice.

Conceptual basis for 4D cadastre

Land administration domain model for utility networks

Before we start the analysis of 3D/4D cadastre, it is important to discern between the aims of a physical representation of the spatial object, and a legal registration of the space needed by the physical objects (Fig. 2). The Land Administration Domain Model (LADM) is used to outline the ideas (Van Oosterom and Lemmen, 2006; ISO/TC211, 2009). The LADM attempts to achieve standardization in the area of cadastral data, provides common definitions for land information and facilitates the effective use, understanding and automation of land related data, thereby enhancing data sharing.

The LADM has defined a class LA_LegalSpaceNetwork (legal space for utility networks) which is associated with external classes for physical utility networks. This extended model gives a good idea of the relation between physical and legal representation of a real object. At this stage, differences between physical and legal objects in the model of Fig. 2 should be recognized. Boundaries of the legal objects (rights) do not necessarily coincide with physical objects (as is in underground utilities), therefore it is not the utility network which is registered in LADM but only the legal space (2D/3D) related to the utility network. Since there is a strong relationship between the represented legal object (maintained by the cadastre) and the represented physical object (maintained for each separate network by the owner), the physical and legal representations should be updated consistently within a given amount of reasonable time when a utility network is updated (Groothedde et al., 2008).

Concept for the 3D cadastre

From a conceptual point of view, one of the foundations of the land parcel based cadastre is that there must be no gaps or overlaps in the spatial representation of the parcel coverage. A planar partition of the earth surface implies that property volumes defined by the space columns above and below the ground surface parcel also form a partition of space. The same foundation (a partition of space with no overlaps or gaps) is also the basis of the conceptual thinking with respect to 3D cadastre (Stoter, 2004). The most advanced implementation would be a system supporting a complete 3D topological structure based on volumes, faces, edges and nodes, as extension of the current systems based on a 2D topology with faces, edges and nodes; however for practical reasons (Stoter et al., 2004) this conceptual view is not necessarily directly translated into an equivalent 3D implementation.

The main objects in cadastral registers with 3D characteristic are apartments, complex constructions, above ground utilities and underground constructions such as tunnels, shopping malls and utilities. Changing over time, currently individual apartments are usually not visible on the cadastral map, only the outline of the apartment building as related to the ground being visible. However, the rights are attached to the individual apartments and some countries, e.g. Argentina, Spain, USA/South Carolina (Van Oosterom et al., 2005) and some municipalities have developed solutions for 3D/volumetric registration of individual units as shown in Fig. 3. Often it is possible to access (analogue or digital) drawings of the apartment building showing the individual units. But this is not integrated with the cadastral map. However, the (physical) building registration in more and more countries is geo-referenced and contains the 3D spatial description of apartment units to which the cadastre could refer. As we will see a similar approach could be taken for the registration of rights on utility networks, that is, refers to the source of physical information on the utility network (geometry).

In the short term a practical solution for the implementation of a full 3D cadastre could be to use the 2D parcels as basis for the partition of space (with their implied column volumes), but to subtract from this the specific cases of volume parcels with a 3D description, e.g. in the form of a polyhedron. Because it can have major technical and legal implications when implementing such a 'simplified' full 3D cadastre, and because it does change the land parcel based systems, Stoter (2004) concluded that a hybrid cadastre could be feasible in the short term. The Land Administration Domain Model (LADM) supports both 2D and 3D parcels and define in the transition zones between 2D and 3D the so-called 'liminal parcels' making sure that the 2D and 3D representations do fit well (ISO/TC211, 2009).

Concept for the 4D cadastre

The conceptual foundation of a 4D cadastre is again the partition concept: no overlaps or gaps in the registered rights (Van Oosterom et al., 2006). In this case it is not only space which is con-

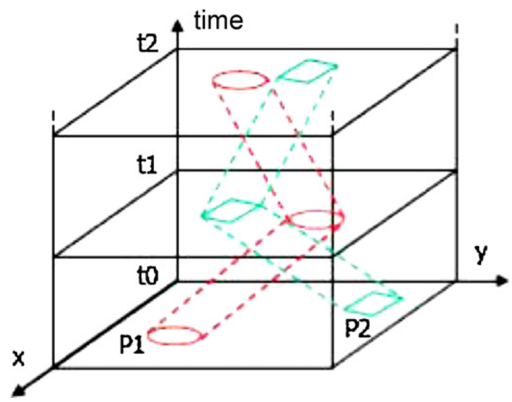

Fig. 4. Representation of two moving objects in integrated treatment of space (2D) and time.

sidered, but also the time dimension. So, every right is attached to a primitive in 4D space. The boundaries mark the discontinuity in the relationships (rights) between people and land (or space). Represented within a 4D volume primitive, the rights are homogenous. A boundary can be a spatial boundary, in the traditional sense of the separation between two parcels, existing at same moment in time; but a boundary can also be a temporal boundary: e.g. A transfers his right on a parcel to B on March 1st. In theory there could be mixed spatial-temporal boundaries in case of dynamic objects, for example a moving river or coast line as boundary, or impacts of natural disaster. The 4D partition fits very well to our (legal) cadastral thinking on the organization of rights. Due to the continuous movement there are 'non-vertical' walls in the temporal dimension (Fig. 4). Parcels with static geometry generate vertical walls in temporal dimension (see Fig. 1b in "Introduction" section), but rights that move will generate non-vertical walls as boundaries in the temporal dimension.

Cadastral registration of utilities in three countries

The aim of the case study in three countries is to analyse how developments in practice match with the conceptual models for 4D cadastre as described above and to highlight the possibilities and limitations of different approaches. The case study is focused on utility networks only. This infrastructure is located in a part of the parcel; and may cross many parcel boundaries, while most of those parcels will be owned by others than the network manager. The utilities are often subsurface and they have therefore an important 3D characteristic. The cadastral registration of utility networks also show some specific temporal aspects, which are (at a minimum) initial creation, changes during life time (including splitting and merging networks), and finally deletion.

The three jurisdictions selected for the case study are: Turkey, the Netherlands and Queensland, Australia. Turkey has been selected to describe the consequences for utility networks if a land parcel based system is kept unchanged and no legal registration exists for utility networks beyond what is needed to provide insight into the location of the physical objects. The Netherlands has been chosen for an approach in which the utility networks are legally registered independently from cadastral parcels and also separately in a physical registration. Finally, in Queensland it is possible to establish 3D cadastral parcels without maintaining a physical registration, or a complete network.

Questions that are analysed in the case study are:

- Related to registration:
  - o How is ownership of utility networks established?
  - o Is the network considered a real estate (i.e. legal registration) object?
  - o Can a cadastral survey or a 3D description be added to deeds where ownership to networks is established?
  - o Does a physical registration of utility networks exist?
- Related to spatial modelling issues:
  - o Is the 2D representation of the utility network visible on the cadastral map?
  - o Is the 2D representation of an affected legal area visible on the cadastral map?
  - o Does the cadastral map provide a complete overview of all networks?
  - o Is the 3D representation of networks available on the cadastral map?
- Related to spatial and temporal queries:
  - o Is it possible to spatially query utility networks in 3D in the cadastre?
  - o Is it possible to perform the query: 'who is the owner of this utility network at any specific moment in time'?
  - o Can temporal information be obtained from the cadastral register?

The analysis is performed in "Cadastral registration of utilities in three countries" section and the answers to the questions are summarised in "Results and discussion" section.

Turkey

Physical registration

Physical registration of utilities is not organized at national level in Turkey. Since underground network itself is not registered, cadastre does not provide geometric information for utilities. Several organizations and operators are responsible for installing and maintaining utility networks. In most situations, however, data sharing with respect to spatial information of the networks is weak. To provide coordination between different network operators within large 500,000+ cities, a law (number 3030) was put into practice and the Infrastructure Coordination Center, AYKOME, was established in 1984. It is the responsibility of the AYKOME to plan, coordinate and inspect the projects for water, electricity, tramway, subway, gas, telecommunication, etc. The registration of utilities is done by local governments through AYKOME based on the law which states that it is compulsory to establish AYKOME if population of the municipality is larger than 500,000; otherwise, each utility operator has its own registration. AYKOME does not access external utilities' databases, but maintains its own database of network data within the municipality. That is, it copies the data. The primary objective of the establishment of AYKOME is to determine how space is occupied by public infrastructure objects in cities. When a request for excavation is received by AYKOME, the area of interest is marked on a map to determine existing underground structures. In addition, depending of existence of data, depth information can be supplied to the excavator. AYKOME also determines if or when the excavation may take place and how much the excavator has to pay for information delivered. The whole process, from request to information delivery, takes around 2 weeks.

The graphs in Figs. 5 and 6 have been produced as a result of a study carried out to determine current situation of underground utility networks in Turkey (Karatas, 2007). In this study, 155 utility operators were investigated with regard to accuracy of positional data. 80 of the 155 operators are responsible for establishing and maintaining water and wastewater utilities, 36 operators are responsible for underground communication cables and the remaining 39 are responsible for underground electricity cables. As seen from Figs. 5 and 6, the location of the underground

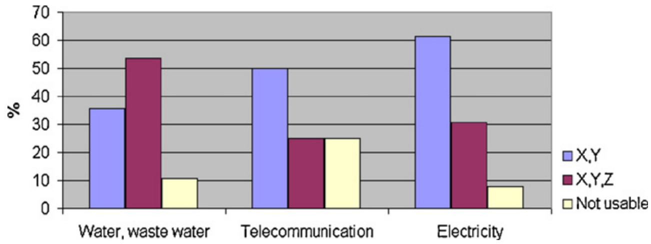

Fig. 5. Coordinate dimension of available utility data.

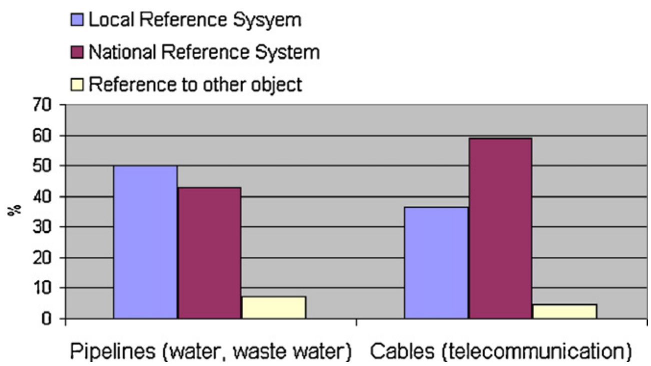

Fig. 6. Spatial reference system of available utility data grouped into pipelines and cables.

networks is, in large extends, still in a local reference system represented with 2D coordinates. *Z* values of utility networks, when available, can be either absolute or relative to the surface. Additionally, available documents that describe previously existing pipelines are often insufficient/incomplete.

Apart from AYKOME, some municipalities have also developed projects to maintain information for utilities on their territories with the help of GIS (geographical information systems). Information on the position of underground utilities was collected by surveying on site or by digitizing paper maps and documents. Fig. 7 is an example from a municipality in Istanbul. It shows natural gas and water supply pipelines together with other cadastral data such as parcels and buildings. GIS software is used as application platform to register underground utilities. Utility layers in this system include attributes such as utility ID, length, diameter, type and pressure (Bitenc et al., 2008).

Legal registration

In Turkey, underground objects are not considered as real estate and therefore they are not described in transaction deeds nor registered in the cadastral register. Moreover, many underground objects, including utility networks, are located under public lands such as roads. According to Article 16 of Cadastre Law (number 3402), public lands such as roads, squares and bridges are only shown on the cadastre map but not registered. Hence, the ownership situation of utility networks crossing public lands remains unrecorded. Three cases can be distinguished for the representation of the legal status of utility networks crossing private property (Doner and Biyik, 2007):

- The owner of the underground utility is entitled to use the space above or below the surface parcel by means of limited rights such as superficies and easement rights. If easements rights are not applied to the full parcel, 2D drawings can be added to the deeds to describe the location of the underground objects. However, these drawings are only available as separate documents and not digitally linked to records describing the associated rights in land.
- The person who holds a utility network is also the owner of the surface parcel (for example the municipality). No limited rights are registered. In case of expropriation before construction of the utility, the situation is the same because ownership of the parcel passes to the owner of the network.
- The owner of the surface parcel is forced to tolerate an underground construction unless there is justifiable objection against

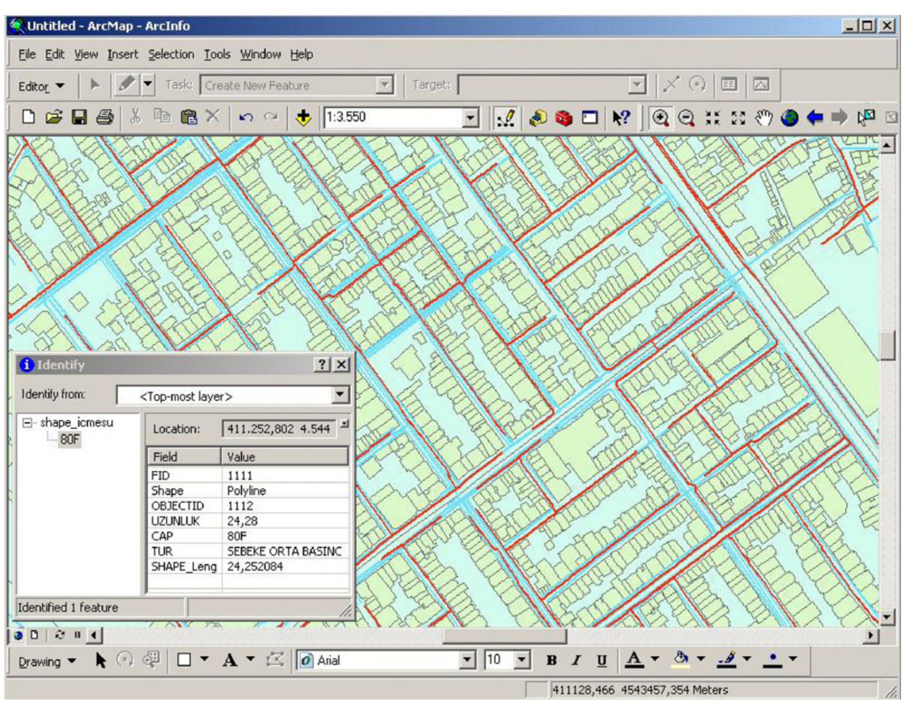

Fig. 7. Network map of gas (red) and water (blue) supply pipelines together with cadastral data. Translation of some of the expressions: 'Uzunluk' = 'length', 'cap' = 'diameter', 'tur' = 'pressure'. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

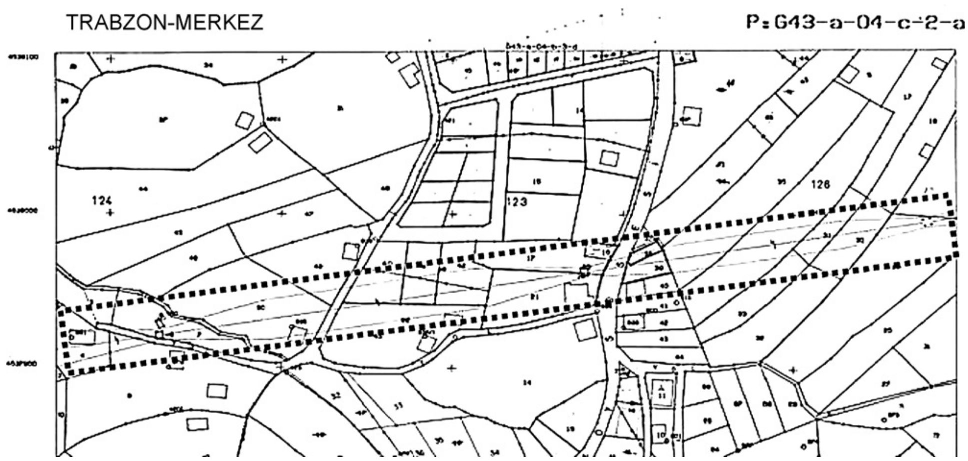

Fig. 8. A cadastre map with high voltage power line (from Demir et al., 2008).

this usage. In this case, the person using space above or below the surface is not owner of the surface parcel and has no right on the surface parcel. Also the situation is not registered and therefore not known in the cadastral register. Since utility networks are generally near to parcel surface, this case may be more faced in case of underground constructions built for transportation purposes such as a tunnel for metro.

In all cases a utility network is not registered as a legal object itself above, on and below the surface. AYKOME maintains physical descriptions of networks but does not deal with registration of rights associated with them. For the first case, an indication of the existence of these objects can be found by examining the limited rights that are established on surface parcels intersecting with a physical object. For the last two cases, no information can be found in cadastral records about the underground physical object.

At this stage, an exception is provided for high voltage power lines. The whole geometry of a high voltage power line is drawn on the cadastral map if the line crosses several parcels (see Fig. 8). Easements are established, and affected areas are presented in 2D in the deeds. However, the high voltage power line is not a legal object itself; therefore, it is not recognized as real estate in cadastre.

As a consequence the cadastre in Turkey does not show a complete picture of the ownership situation of utility networks. Only for privately owned parcels that are crossed and for which a real right was established it is possible to view the ownership situation.

The Netherlands

In the Netherlands two registrations of utilities are maintained: a physical object registration (geometry and relevant characteristics of the utility) and a legal registration (ownership and other rights). In both the physical object and the legal registrations the Netherlands' Kadaster plays a central role, although there is no direct link between both registrations.

Physical object registration of utilities

The first registration has the oldest roots. The need to protect underground cables and pipelines against damages, triggered the establishment of the so-called KLIC's (Cable and Pipeline Information Centre) in the 1980s. These centres were private institutes, and the result of the cooperation between several utility operators. The KLIC's did not (and still do not) register the networks themselves, but maintain a grid covering the Netherlands. The grid cells are 500 m by 500 m and the KLIC's register the network operators

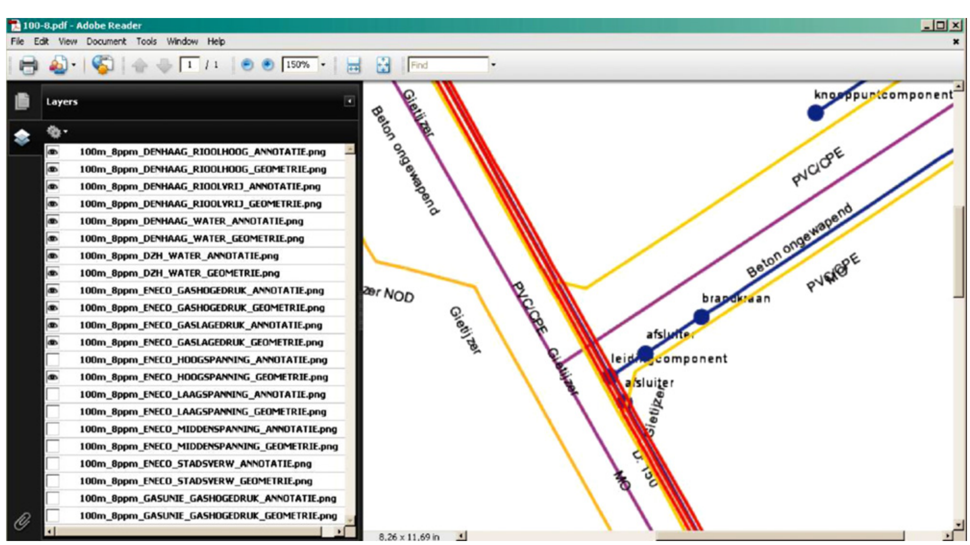

Fig. 9. PDF file with available utility networks in a given area.

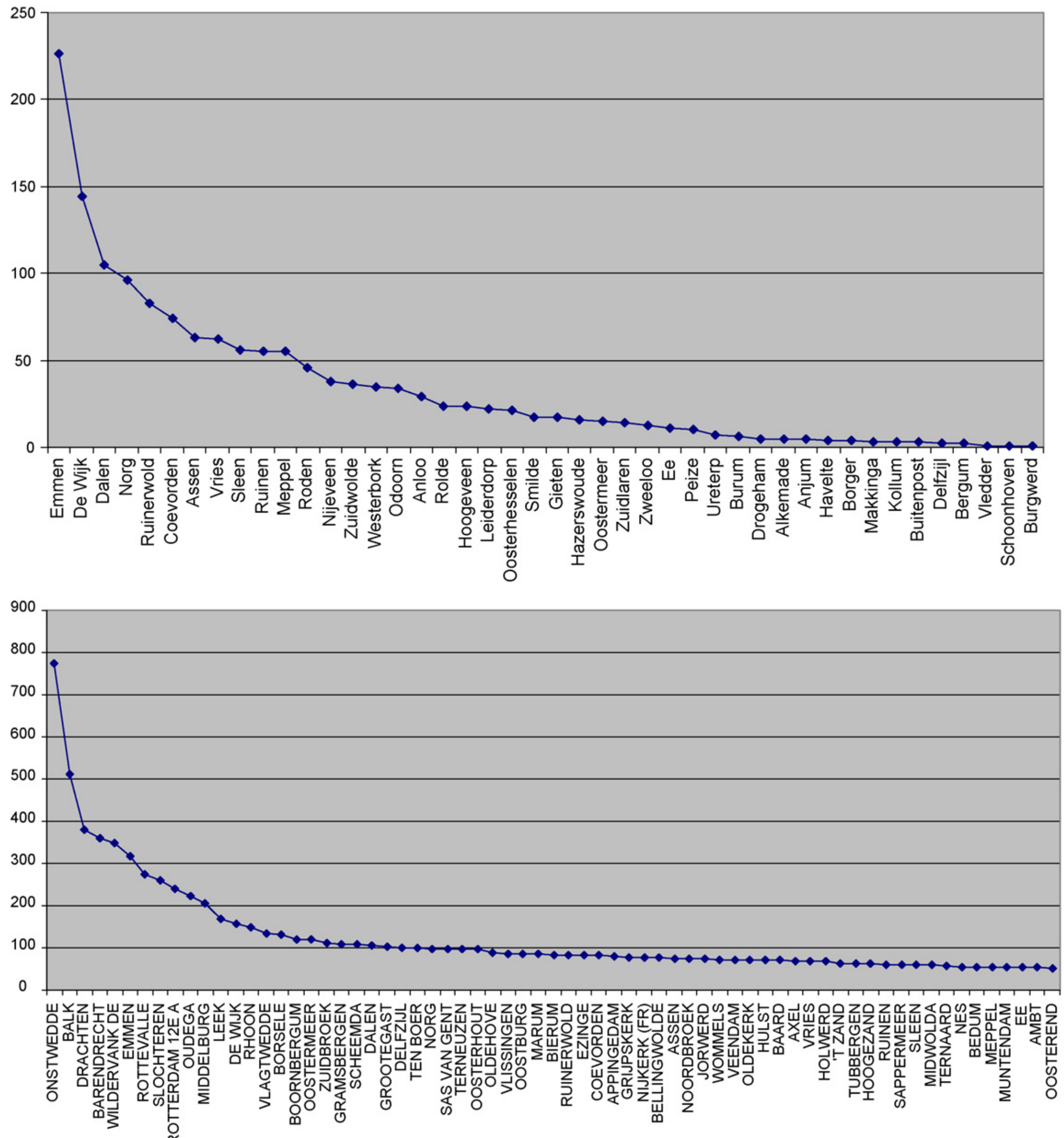

Fig. 10. The occurrences of 'OB' codes per cadastral municipality. Top diagram: 2003, all municipalities with registered OB codes are shown. Bottom diagram: 2008 municipalities with 50 or less OB codes registered are not shown (175 municipalities in total).

who have cables and pipelines in a specific cell. The aim of this data set is to provide easy access to the relevant parts of network maps kept and maintained by the operators themselves. In short, the system works in this way: if one plans works in the subsurface, (s)he may contact the KLIC, providing the exact location of the works. The KLIC notifies all the known network operators in this area, and these will send their own (paper or digital) map of the relevant part of the network directly to the applicant (Fig. 9). Alternatively a network operator may also choose to send a surveyor to the location to indicate to the contractor the location of their infrastructure. Keeping the location information at the network operators and making them responsible for providing location information of their networks, leave the responsibility for maintaining the exact location information of the utility networks to the operators.

In 2008 the Dutch parliament agreed on an act to regulate this information exchange. The Act on Information Exchange Underground Networks (*WION*, *Wet Informatieuitwisseling Ondergrondse Netwerken*), transfers the actual KLIC service to the Netherlands' Kadaster. Furthermore it enforces all network operators to take part in this system of digital information exchange and all contractors to make inquiries through it before starting the work. An integrated information model for cables and pipes was developed (IMKL) and corresponding message exchange model (BMKL) for requesting network information by the contractors (www.kadaster.nl/klic, in Dutch). In the near future a new computerized system will be introduced. From that moment, after the inquiry is received by the Kadaster, the Kadaster computer will automatically send a request for information to the network operators. After the Kadaster has obtained the information, the inquirer will receive one integrated map in a PDF format (Fig. 9). For this system to work, a requirement is that the maps of the network operators are digitally available in the national reference system according to IMKL and available via a web mapping service (WMS). Main characteristic of this registration is that the spatial information on the network is still provided by the network operators.


kadaster-on-line
Mijn Kadaster Home Contact Woordenboek Documentatie Help

Kadastraal bericht object

Dienst voor het kadaster en de openbare registers in Nederland
Gegevens over de rechtstoestand van kadastrale objecten, met uitzondering van de gegevens inzake hypotheken en beslagen

Kadaster

Betreft: NETWERKEN ROTTERDAM T 1 19-11-2008 15:59:03
Toestandsdatum: 18-11-2008

Kadastraal object
Kadastrale aanduiding: NETWERKEN ROTTERDAM T 1
Grootte: 1 ca
Omschrijving kadastraal object: NETWERK Jaar: 2008
Ontstaan op: 17-8-2006

Publiekrechtelijke Beperkingen
Het kadastraal object is onbekend in de gemeentelijke beperkingenregistratie. Er kan geen informatie over gemeentelijke beperkingen van de gemeente NETWERKEN ROTTERDAM worden geleverd. Neem contact op met de gemeente NETWERKEN ROTTERDAM.

Gerechtigde
EIGENDOM
COMMUNICATION INFRASTRUCTURE FUND (CIF) B.V.
De Beek 18
3871 MS HOEVELAKEN
Zetel: HOEVELAKEN
(Gerechtigde is betrokken als gerechtigde bij andere objecten)

Recht ontleend aan: HYP4 54887/ 98 d.d. 20-6-2008
Eerst genoemde object in brondocument: NETWERKEN ROTTERDAM T 1

Einde overzicht
De Dienst voor het kadaster en de openbare registers behoudt ten aanzien van de kadastrale gegevens zich het recht voor als bedoeld in artikel 2 lid 1 juncto artikel 6 lid 3 van de Databankenwet.

Fig. 11. Example of registered network (telecommunication) in Kadaster-on-line. The layout of the screen is exactly the same as for parcels. Translation of some of the expressions in the second section: 'grootte' = 'area', 'omschrijving' = 'desciption', 'publiekrechtelijke beperkingen' = 'public restrictions', and the third section 'gerechtigde' = 'holder of the right', 'eigendom' = 'ownership'.

Legal registration

The legal registration differs fundamentally from the physical registration. The legal registration of networks by the Netherlands' Kadaster had to be established after a judgment of the Dutch Supreme Court in 2003. Until that moment the legal qualification of networks was disputed: were they movable or real estate? In practice some networks were transferred as being movable property (chattel), and therefore not registered. If networks were considered to be real estate, the rule *superficies solo cedit* (vertical accession), stating that fixtures will follow the ownership of the land, offered serious problems in case a network crossed several parcels. A strict interpretation of this rule would mean that the ownership of the network was divided among the owners of all parcels the network will cross. However, some lawyers argued that a network could be considered to be part of a major construction on a 'mother' parcel, like a power station or a transformer (horizontal accession). In this last opinion the ownership of the complete network could be transferred by transferring one 'mother' parcel.

Specifically for telecommunication networks, the act on telecommunication provided the rule that the ownership of the network remained with the operator. In that special case, the whole network was owned by the operator. The construction of the network in the land did not change the ownership of the network. Therefore the Act gave an explicit exception for the rule *superficies solo cedit*. However this exception did not apply for other networks, such as gas and electricity.

Summarising, ownership on networks was not unambiguously nor clearly registered before 2003. Cadastral identifiers were only known for cadastral parcels. Personal rights (contracts) or public law permits allowing the construction of a network in land that is not owned by the network manager were not registered at all (Ploeger and Stoter, 2004). In case limited real rights (leases or easements) or restrictive covenants were established for the network on crossing parcels this evoked a cadastral registration. But these rights were only established on the complete parcels, and the geometry of the network remained unregistered. The cadastral register did (and still does) offer the possibility to register the presence of an underground object (*Ondergronds Object*) in a parcel, by marking the parcel with a code ('OB'). However an analysis of the occurrences of this code (Fig. 10), showed no relation with the actual number of networks in the areas that might be expected: only a very limited number of OB codes are registered in big cities or in municipalities located in the busy western-part of the Netherlands.

Instead most OB codes are registered in the less populated northern part where, among others, the biggest producer in natural gas and oil in the Netherlands, the Dutch Oil Company NAM is operating though its pipelines. Therefore it may be concluded that the use of this registration is heavily influenced by personal preferences. Since Fig. 10 contains snapshots in time, we can also see that the use of the code has become more well-known since 2003; the query of the 2003 cadastral database yielded 1.493 registered OB codes; the query of the 2005 cadastral database 3.872 (not shown) and the query of the 2008 database resulted in 11.438 registered OB codes.

Several solutions could have been chosen to establish the network ownership, even for one network. Consequently the cadastral register could not offer a complete overview of the ownership rights of networks, nor indicate the affected parcels.

The 2003 judgment of the Supreme Court on the taxation of the transfer of ownership of two telecommunication networks made clear that (underground) networks are real estate objects. Consequently, according to the general rules of the Dutch Civil Code, the ownership has to be transferred by a notarial deed registered in the public registers. A second consequence of this judgment is therefore that the cadastral registration of the ownership on these networks is required. However, it should be noted that the judgment itself does still not solve the ownership question of networks other than telecommunication networks. The legislature had to respond and indeed in the beginning of 2007 the Dutch Civil Code got a new provision, stating that a network 'of one or more cables or pipes, for the transport of solid material, fluids or gas, energy or information, that is constructed in, on or above the land of an other person, is owned by the legitimate constructor, or its legal successor.' (Book 5, article 20, section 2, Civil Code). A 'legitimate constructor' means that the constructor has the right (e.g. because

Fig. 12. Zoom-in on a network map.

of a lease, an easement or a contract) to put the cable (or pipeline) in the land of another.

Till 2007 the Cadastre Act lacked a provision for a cadastral identity for networks as such. Therefore the Kadaster designed in 2003 a provisional method for the registration and transfer of telecommunication networks in collaboration with the Dutch notaries. The deed had to refer to a ground parcel (a *reference parcel*), e.g. the parcel where the starting point of the network could be located. In the cadastral registration, a reference to the network, its owners and other rights on it, would be made by use of this parcel number. One should note that it was not needed that the network owner would also be the owner of the reference parcel. Therefore the use of this parcel number was just an administrative method for registration of telecommunication networks within the cadastre (Ploeger and Stoter, 2004).

The actual legal registration of all networks is based on the temporarily method developed for telecommunication networks in 2003. In 2007 the Cadastral Act was changed in such way that a network as such could get its own number, like a parcel. This identifier consists out of the prefix '*Netwerken*' (networks), the name of the cadastre office of the area where the network is located, a letter that refers to the type of network, and a succeeding number. For example '*Netwerken Rotterdam T 1*' is the first telecommunication network registered in this office of the Dutch Cadastre (see Fig. 11).

An unregistered network (existing before 2008 or newly constructed after 2008) will be registered by the registration of a notarial document in the registry of deeds. This document must include a network map. The network map is made by the Kadaster itself by an overlay of the network geometry as supplied by the network operator on the cadastral map. The network operator has the choice to represent the network as a line or a polygon (see Fig. 12) and to assign an accuracy measure to the location information (which will not be visible from the map). The network map does not provide 3D information (Ploeger and Stoter, 2007).

To understand the meaning of the network map, one should notice that:

- The network map aims to identify the network as an object of property rights, but does not aim to provide the exact geometry or location of the network. It can therefore not be used to query which parcels are crossed by the network.
- The Kadaster is responsible for the location information of *parcels* on the cadastral map. The network map is based on the information provided by the network operator. The Kadaster will *not* check the accuracy of this information. Nor it checks if the network really exists! Therefore the Kadaster is not responsible for the location information of *networks*. This also means that networks that are planned or partially constructed may be registered.
- The network map, which is currently only available with the deed and not with the current cadastral map, is a 'snapshot' of the situation at the date of registration. That means not only that the size and location on the map is as per the date the overlay was made, but also the cadastral map (and therefore the parcels and parcel numbers) is as at a point in time. If one of the intersecting parcels is subdivided (in which case the newly created parcels will get new numbers), this will not change the registered network map. Therefore, the older the network map, the bigger the chance that an actual parcel cannot be traced on the map. However when the network itself changes in size, or location, a new network map needs to be registered.
- A change in the physical network (extension or reduction) means that a new notarial deed and a new network map must be registered and the 'old' network map must be removed. However a change in the network is not always known by the operator. For example cables might move up to 1 m in the wet soils of the Netherlands. In addition, at the moment of construction, the actual location might have been moved compared to the planned location. These revisions have not always been included in the database of the operators.

Once registered, in future transactions the deed needed for the transfer of the ownership of the network, or the establishment of limited rights on it (e.g. a mortgage), will refer to the cadastral identifier of the network, like the reference to a parcel number in the case of the transfer of a piece of land. From 2010, all networks dating from 1950 onward are required to be registered.

Queensland, Australia

Physical registration

In Queensland, the utility corporations maintain their own records of network details, with the state land registry maintaining a record of any easements that are necessary to allow the network to cross private land. Where the network crosses state land, no easement is registered. The bounds of an easement are defined on the survey plan of the burdened parcel, with the beneficiary (network owner) being noted on the title document.

In the case of underground networks, a national non-profit organization, known as "Dial Before You Dig" maintains a service in order to prevent accidental damage to underground assets, or injury to excavators. This organization maintains a spatial index of the extents of its member corporations' regions of interest to direct public enquiries to the appropriate corporations. It provides a single point of call, but does not maintain a database of detailed information on the positioning of assets. Member corporations include municipal councils, electricity, water, gas and telecommunications utilities and other interested parties.

Legal registration

Queensland, Australia offers many possibilities to establish ownership on objects crossing several parcels. For example, easements can be registered for public utilities such as the supply of water, gas, electricity, telecommunication facilities, and can be drawn on volumetric survey plans with their own geometry. Therefore they may cross several parcels. These easements can also be restricted vertically in both depth and height and defined as volumetric easement on a volumetric plan. Vertical restrictions of the easements are described on these volumetric plans with reference to Australian Height Datum together with details of the Permanent Mark on which this is based. There is little restriction on the shapes that are allowed in defining 3D cadastral objects, including ease-

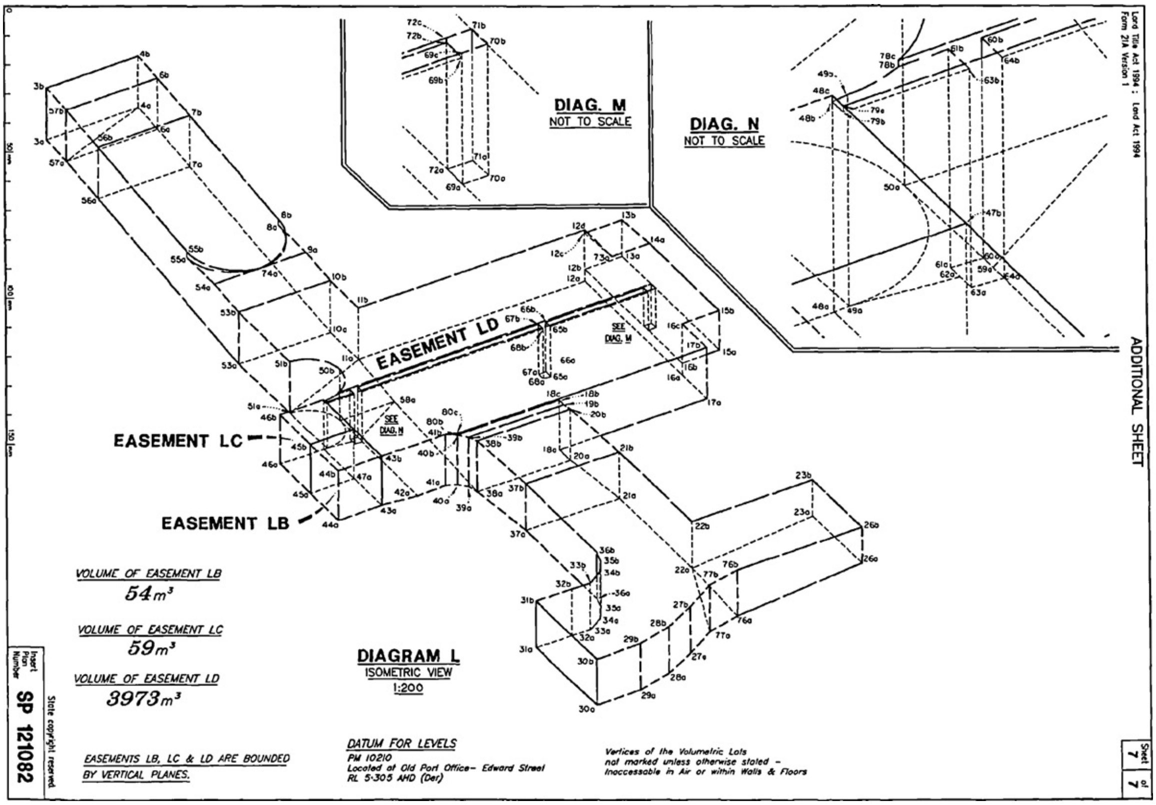

Fig. 13. Example of volumetric survey plan for easement.

ments, provided that an unambiguous definition of the extents can be determined. In practice, the survey plan must contain plan, elevation and isometric views that make the shape and location of the parcels clear, with the necessary bearings and distances annotated (Fig. 13).

In Queensland, all secondary interests such as easements, are initially defined when the base parcel is surveyed. The rule is that each secondary interest parcel is defined as existing within a single base parcel, and therefore cannot cross a base parcel boundary. As time passes, a 2D base parcel may be subdivided, with the secondary interest parcels not necessarily being redefined, leaving secondary interest parcels which cross base parcel boundaries (Fig. 14).

Current practice is that where a secondary interest (easement) is restricted to a 3D region excised from a 2D base parcel, the base parcel retains its 2D representation (Fig. 15). For this reason, it could be expected that subdivision of base parcels may lead to a 3D secondary interest intruding into more than one base cadastral 2D parcel in the future. By contrast, where there is need to reserve space in a building for infrastructure, the full volume will be subdivided with the infrastructure parcels being properly constructed 3D parcels which do not overlap other 3D parcels (and are therefore not seen as secondary interests).

The advanced possibility to establish real rights on space, not necessarily restricted to the division of land parcels, offers big improvements for establishing ownership rights on utility net-

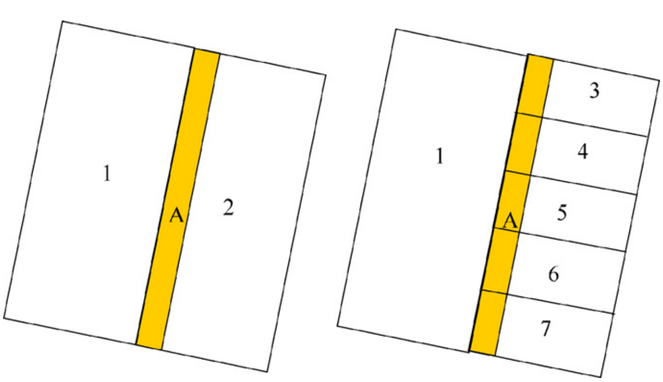

Fig. 14. In the situation on the left, easement A is defined over parcel 2. On the right, parcel 2 has been subdivided to form parcels 3–7, with easement A applying to them all.

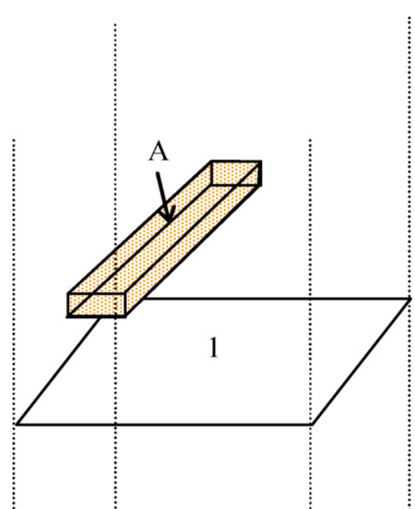

Fig. 15. A 3D easement 'A' as a secondary interest in a 2D parcel '1'.

Fig. 16. Cadastral map from Queensland with the footprints of the cross-river tunnel (in purple) and various easements (in yellow). Road parcels are brown and base parcels are green. Red indicates strata title parcels. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

works. However, only footprints of easements on surface are currently available in the cadastral database in Queensland (see Fig. 16).

In general, only where a network passes under/over a property parcel is its extent defined as a volume of space. Where a road or watercourse parcel is involved, a gap is left in the network (because this is also owned by the government). Thus it would not be possible to concatenate the individual parcels into a complete network. Note in the southern part of Fig. 16, how the tunnel is broken at each cross road, and at the north, the tunnel parcels stop at the river's edge. By contrast, it is also noted in Fig. 16, that where the tunnel comes to the surface within a road, its extents are defined.

There is a separate survey plan drawn for every base parcel that is affected by the network, as can be seen in Fig. 17, which is an example from the region shown in Fig. 16 (lot 837 in the north, adjacent to the river).

Generally, any changes to the network size, shape or configuration are registered by the drawing of a new survey plan, replacing one or more existing plans. However lot 837 (Fig. 17) exhibits an unusual feature. The irregular vertical edge in the isometric drawing is defined by the surface parcel in its X/Y positioning and shape. This surface parcel itself is defined by the high water mark of the river. Thus this 3D below ground boundary is subject to movement as the natural boundary is affected by 'slow and imperceptible' accretion or erosion at the surface.

Results and discussion

As we can see in Table 1, only the legal registration of utility networks in the Netherlands provides a way to register the network itself in the cadastre, including the geometry of the object. In the cadastres in both Turkey and Queensland, the network can only be traced via real rights which may or may not have been established for the networks. Therefore the cadastral map in both Queensland and Turkey will not give a complete overview of all utility networks, since it depends on a specific situation how the ownership of the network is established. This may be even different for the same network.

A 2D representation of a parcel is a conceptual, database object to indicate the extent of real rights. Parcels are not physical objects, and the boundaries are not always easily traceable in the terrain. Only when overlaying the parcel boundaries maintained in the cadastral database with topography, the real estate objects can be located by relating them to physical objects in the terrain. A full 3D cadastre extends this concept into 3D: a volumetric parcel is also a conceptual object, not necessarily visible in reality. Therefore it

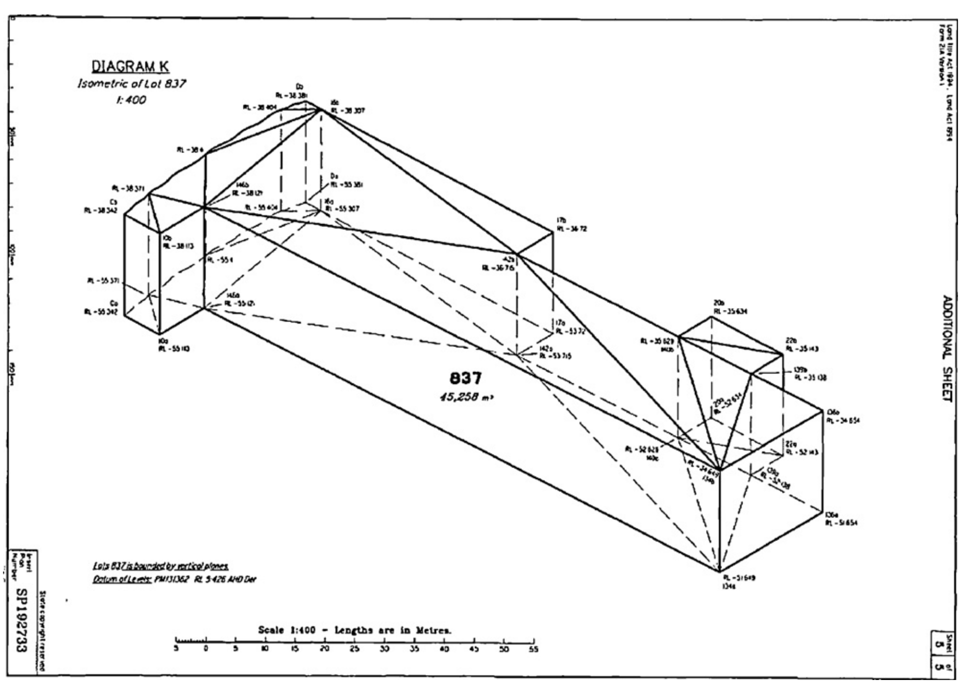

Fig. 17. Survey plan showing part of the tunnel network passing under a property parcel.

Table 1
Case study utility registration in three countries.

Question	Land		
	Turkey	The Netherlands	Queensland
How is ownership of utility networks established?	By means of limited rights established on surface parcels	Owned by legitimate constructor	Owned by constructor
Is the network a real estate (i.e. legal registration) object?	No	Yes	Not usually. The cross-river tunnel and some sugar cane tramways are exceptions
Can a cadastral survey or other 3D description be added to deeds where ownership to networks is established?	Yes, if limited rights are applied to certain part of the surface parcels, 2D drawings can be added to deeds	Yes, but not compulsory	Yes
Does a physical registration of utility networks exist?	Yes, but not complete	No single register exists, but information on underground networks is made available via a national service	No single register exists, but information on underground networks is made available via a national service
Is the 2D location of utility network itself visible in cadastral map?	No, but high voltage power lines can be seen on cadastre map	No, but on a separate registered network map	Usually not. Part of some networks can be seen as collections of easements, but need not be complete (see discussion around Fig. 15). Also the purpose of an easement is not present in a cadastral map
Is the 2D location of affected legal area visible in standard cadastral map?	No, only as separate 2D drawing	No	Yes, but not where the affected area is part of a road, watercourse or state land
Does the standard cadastral map provide complete overview of all networks?	No	No	No
Is the 3D location of networks available in the cadastral map?	No	No	No
Is it possible to spatially query the situations of utility networks in 3D in the cadastre?	No	No	No
Is it possible to perform the query: 'who is the owner of this utility network'?	No	Yes	Yes
Can temporal information be obtained from the cadastral register?	Yes, creation time of the limited rights	Yes	Yes (for history created since 1997)
Are 4D principles used for implementation the 4D space time partition concept? If not, are measurements taken for making sure it is a space time partition?	No/No	No/No	No/No

may be used for other purposes than the registration of ownership on 3D physical objects, for example to establish a safety zone for a tunnel or to assure future view from a building. The concept of a 3D parcel better aligns with the traditional registration of real estate than the registration of physical objects as in the Netherlands. The ownership of a land parcel implies ownership of all physical objects that are attached to the parcel and located within the parcel boundaries. In the same way the ownership of a 3D parcel implies the ownership of all physical objects that are located in the space, e.g. tunnel or utility network. To be able to treat a physical object as one object, it would then be required to establish 3D parcels entailing whole objects.

Queensland provides the possibility to establish 3D parcels. It is possible to provide the titles establishing the real rights with a 3D survey plan, describing the legal space that is affected by the real right. Volumetric survey plans have *Z* values on points which define parcels or easements (referred to as rl—reduced levels), but no points have X or Y coordinates. Horizontal positions of parcels are only defined in relation to their adjoining parcels.

Although Queensland is the only one of the three countries which provides an advanced way to deal with the third dimension of ownership and other real rights, this solution is still partial. This has some serious consequences for the available information on utility networks with respect to 3D. Firstly the interest parcel for a utility network should be located within a single base parcel and therefore cannot cross several parcels, and the network is only visible in the cadastre where it passes though (or above or below) non-government land. Thus it is not possible to define the legal space of the whole network. Moreover, for objects within one parcel the Queensland solution has limitations: Since the 3D information is laid down on paper or scanned drawings, as a 2D visualisation, the 3D information cannot be interactively viewed. In addition 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, do any edges or faces intersect? Finally 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 the Netherlands, it is possible but not required to provide X, Y, and Z coordinates with a network map when registering the network as legal object. However, only in a few cases, the descriptions actually contain information on the Z-coordinate for utility networks. In addition since the cadastral map is in 2D, the third dimension will not be visible on the map. Consequently, although a 3D cadastral survey or other 3D description can be added to deeds, in practice only few networks are available in 3D which are never shown as such on the cadastral map in the Netherlands.

Finally, if cadastral registrations do allow the registration of real rights on networks such as in the Netherlands, the question arises why not allowing the legal registration of other physical objects such as a tunnel, an underground parking place or an apartment unit in an apartment complex?

Conclusions

Due to the complex management tasks, modelling dynamic and multi-dimensional spatial information has become one of the challenging topics in current cadastres. Since utility networks are the most typical objects with 4D characteristics in a cadastre, the physical and legal registration of utilities in three countries (Turkey, The Netherlands and Queensland, Australia) have been examined in order to analyse the legal, organizational and technical aspects of current practice in an integrated way. Although the countries have remarkable differences, they can all be supported with a 4D cadastral registration. We have proposed a model for management of physical and legal networks: 'physical registration' possibly at the distributed utility network operators (and access via national services) and 'legal registration' at the cadastre. Via the geo-information infrastructure (GII or simply Geoweb) both registrations can be accessed and confronted with eachother. Also update procedures could use the facilities of the GII. The analysis has further clearly shown that the 4D (=3D space + time) cadastre is possible in legal, organizational, and technical aspect.

Legal

In case of utility networks, an approach to improve the current registrations could be to keep the geometry of physical utility networks in the databases of organizations or companies managing each network and refer to this information from the cadastre when needed. The legal objects for utility networks can than be generated in a controlled (regulated) manner from the 3D descriptions of the physical objects. Because of the permanent link, the legal registration can also be better maintained. In our paper, we have adopted the conceptual model of LADM for evaluating this solution. The LADM includes building unit and (utility) network as specializations of LA_SpatialUnit (to which the legal facts are associated).

In the context of this paper, legal impact of a 4D cadastre could only be shortly addressed. We can conclude that the spatial (3D) aspect of a cadastre will only be relevant against a legal background that recognizes the possibility of a stratification of land ownership, although the time aspect as such will be relevant for any system of land administration.

Organizational

The organizational aspects on which are solution is based relies heavily on the used of the GII and to access remote data maintained by another organization. Besides the technical aspects this also requires organizational agreements. When using this approach, it becomes possible to check if there are (unwanted) differences between the 3D physical object itself and the property rights. The registered legal objects may not necessarily coincide with physical objects. For example, in the case of utility networks the rights on the land in which the utility is constructed may not only give the ownership to the utility, but also rights to a certain space, a 'buffer' around the utility. However a link between a physical and a legal registration within the GII enables efficient checking the consistency between the two. Organizational arrangements have to be made to resolve the differences and to make sure that after changes at the side of the physical networks also the legal counterpart is updated (of course in a controlled/regulated procedure).

Technical

From technical point of view (see Döner et al., submitted for publication), the solution for 4D registrations of utilities in the cadastre based on 3D geometry data types and separate temporal attributes is possible. 3D geometric description of utilities together with other spatial data sets such as buildings and parcels can be organized in a spatial database environment. One of the advantages of the environment is that relationships between utility networks and other cadastral objects will be visible. In addition, a spatial analysis within the network and between other data sets is possible in the DBMS environment. Furthermore, utility and cadastral data can be effectively managed in a database while processes on networks such as editing and a visualisation can be performed by using usual procedures of preferred front-end software.

From the research we can conclude that registration 3D and 4D aspects of utility networks in cadastre is more sustainable than current practice, where the third dimensional and temporal aspect are not considered when registering a network. Further it can be concluded that the 3D space and separate temporal attributes approach (state based model) is sufficient to model temporal changes of utility networks. However, it should be noted that, the 4D integrated data type is necessary to model dynamic objects like parcel boundaries which follow the movements of natural features such as coastlines or river borders. Another important issue is availability and quality of 3D data. Height information of future utilities (also for other 3D objects such as apartment buildings) should be provided in absolute manner instead of relative heights with respect to surface since absolute coordinates are more stable and they provide unambiguous definitions of the 3D objects.

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