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Current developments in 3D-cadastre with examples from the Netherlands and the Russian Federation

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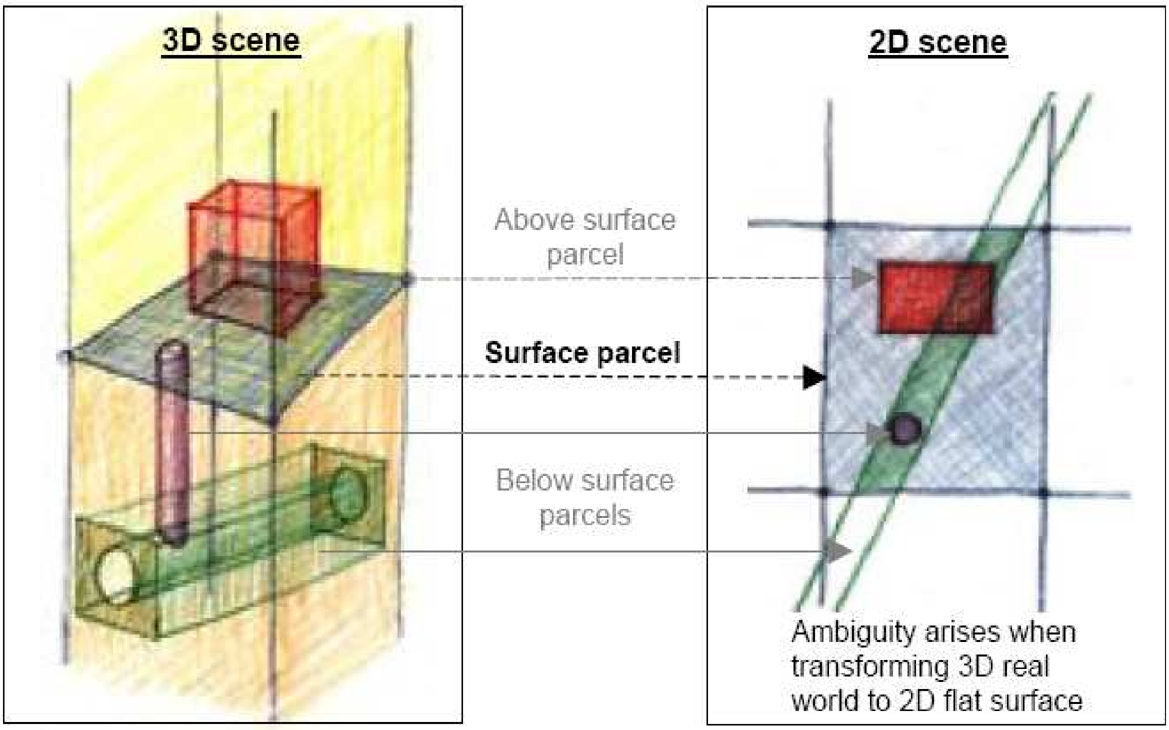
1. Introduction

The world is (at least) three dimensional in our perception although when it comes to representation we have become used to the simplification of the 'reality' into two dimensions (2D). Most situations in a cadastre can be represented in 2D on a map without that this representation causes too many uncertainties or queries. However, with current developments in architecture, registration of apartment rights and underground cables and pipelines the representation of real estate objects in 2D is often no longer adequate in representing unambiguously the 'reality' (Figure 1). In the case of apartment rights a three dimensional drawing is sometimes provided to furnish an idea where in the building these rights are located. Modern technologies, however, allow us increasingly to represent the 'reality' in three dimensions (3D). Technologies for creating and managing 3D-geoinformation have matured while costs for such information and 3D-tools have significantly decreased. These tools enable us to represent the 'reality' in an improved manner. Ongoing developments will allow us to represent the 'reality' in future even in 4D (including time) (Van Oosterom *et al*. 2006) and 5D (including time and scale dimensions) (Van Oosterom and Stoter 2010).

Figure 1. 3D versus 2D representation of objects



As shown in Figure 1, objects of property rights refer to a space above or below the Earth surface. The fact that several spaces of legal objects are located above, below or on the same plot can in practice lead to ambiguities in 2D registrations. The increasing complexity of infrastructures and densely built-up areas requires a proper registration of the legal status (private and public). This can only be provided to a limited extent by the existing 2D registrations. Publication of such 3D-property relations has forced cadastres around the world to find solutions for a kind of 3D registration (Stoter, Louwman, Ploeger and Van Oosterom 2011). In the past decade various scientific activities paralleled with developments in practise have been conducted related to 3D-cadastres (Ploeger and Van Oosterom 2011).

However the concepts *3D-cadastre* and *3D-parcels* are still ambiguous: what exactly is (or could be) a 3D-parcel is dependent on the legal and organisational context in the specific legislation. A 3D-parcel is defined by the FIG joint Commission 3 and 7 Working Group on 3D-Cadastres (2010-2014) (www.fig.net) as the spatial unit against which (one or more) unique and homogeneous[1] rights (e.g., ownership right or land-use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration System. A 3D-parcel is a *legal object* describing a part of the space. Often there is a relationship with a real world/physical object, which can also be described in 3D. One should be aware of the difference between these two types of objects and that the focus in the context of 3D-cadastres is on 3D-parcels (spaces of legal objects). In general one could state that in nearly all jurisdictions 3D-parcels can be registered, but in most cases these 3D-parcels are (or even limited to) apartment units and in most cases without explicit 3D geometries. Despite all research and progress in practice, no country in the world has a true 3D-cadastre, the functionality is always limited in some manner; for instance only registering of volumetric parcels in the public registers, but not included in a 3D-cadastral map, or limited to a specific type of object with *ad hoc* semi 3D-solutions (e.g., for buildings or infrastructure) (Ploeger and Van Oosterom 2011).

There are several 3D-cadastre scoping options, which need to be investigated by the FIG Working Group on 3D-Cadastres (2010-2014) in more detail and the result will define the scope of the future 3D-cadastre in a specific country (Van Oosterom, Stoter, Ploeger, Thompson, Karki 2011):

1. What are the types of 3D cadastral objects that need to be registered? Are these always related to (future) constructions (buildings, pipelines, tunnels, etc.) or could it be any part of the 3D space, both airspace or in the subsurface?
2. In case of (subsurface) infrastructure objects, such as long tunnels (for roads, metro, train), pipelines, and cables: should these be divided based on the surface parcels or treated as one cadastral object. In case of subdivision, note that to all parts rights (and parties) should be associated.
3. For the representation (and initial registration) of a 3D cadastral object, is the legal space specified by its own coordinates in a shared reference system (as is the practice for 2D in most countries) or is it specified by referencing existing topographic objects/boundaries.

Note that there can be a difference between the 3D-ownership space and the 3D-restriction space; for example one can be owner up to ±100 m around the earth surface, but only allowed to build from -10 to +40 m. Both result in 3D-parcels, that is, 3D spatial units with rights, restrictions and responsibilities attached. The ownership spaces (parcels) should not overlap other ownership parcels, though they are allowed to overlap other space especially restriction parcels.

Important cadastral remarks that can be made related to the use of 2D registrations and the potential 3D extensions are:

- People are always entitled to *volumes* or *objects* and not to just a surface; and
- 3D-cadastre reconsiders the 2D-parcel as only the base for registration of real estate objects.

In the next section it is discussed how complex situations of rights are handled in the Netherlands and the Russian Federation.

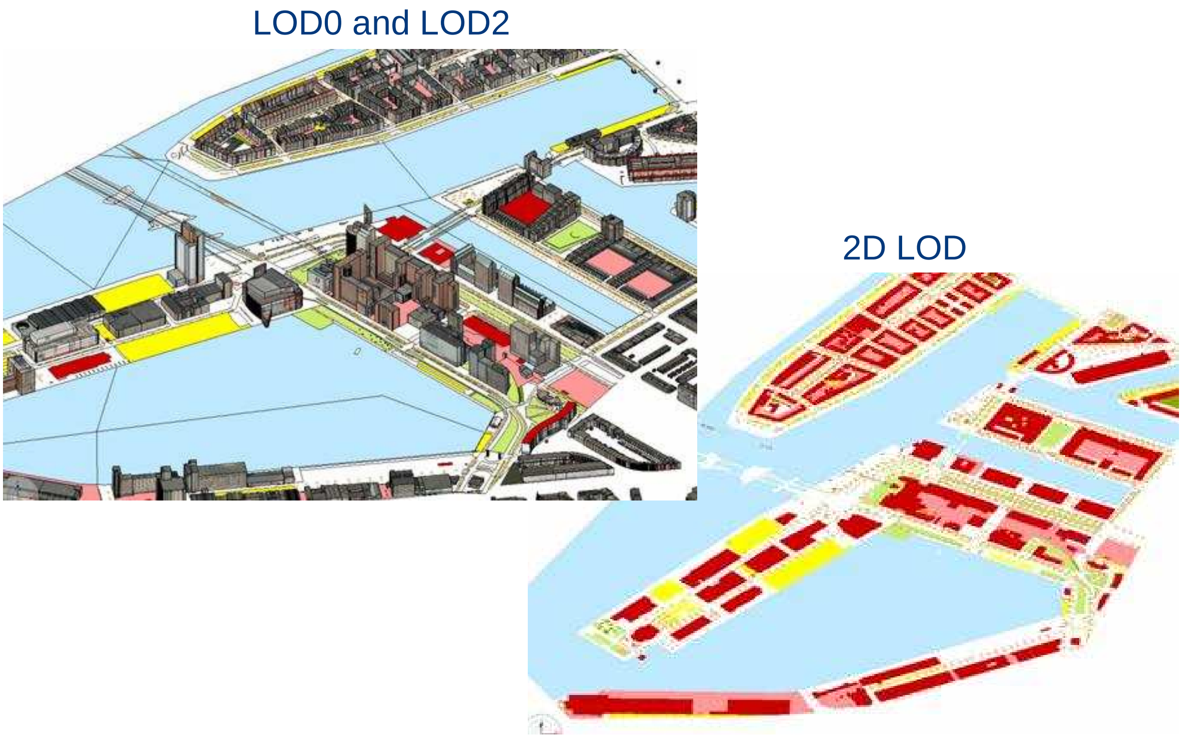
[1] 'Homogenous' means that the same combination of rights equally apply within the whole 3D spatial unit. 'Unique' means that this is the largest spatial unit for which this is true. Making the unit any larger would result in the combination of rights not being homogenous. Making the unit smaller would result in at least 2 neighbour 3D parcels with the same combinations of rights (Van Oosterom, Stoter and Ploeger 2011).

3. Implementation of the 3D-model

3.1 The '3D Pilot' project in the Netherlands

It is clear that not only 3D-cadastre, but also many other 3D-applications are getting important and will be even more so in the near future. The Netherlands' Cadastre, Land Registry and Mapping Agency (Kadaster), Geonovum, the Netherlands' Committee of Geodesy and the Ministry of Infrastructure and Environment initiated a pilot to further advance in the domain of 3D in the Netherlands. In the so-called '3D Pilot', executed between March 2010 and June 2011, more than 65 private, public and scientific organisations collaborated in a non-competitive environment on use cases and a test bed to move forwards 3D-developments. The pilot has resulted in showing the added value of 3D, a national 3D-standard compliant with the Open Geospatial Consortium (OGC) standard CityGML (www.opengeospatial.org/ standards/citygml) that is currently under public consultation. The developed standard integrates the existing 2D information model on large-scale topography with CityGML and it has made 3D-applications tangible in the Netherlands. Furthermore, it is compliant to the Dutch standard. The type of spatial and temporal information necessary and the way in which different users (e.g., notary, real estate agent, water board, utility company, and citizen) utilise this information determines the 3D model. In addition, the pilot has shown the need for a countrywide reference 3D-dataset. Promising results were achieved for generating 3D-topography based on a combination of 2D-topography and high density laser point data. A follow-up pilot is focussing on making the results of the first pilot project ready for use in practice (Stoter 2011).

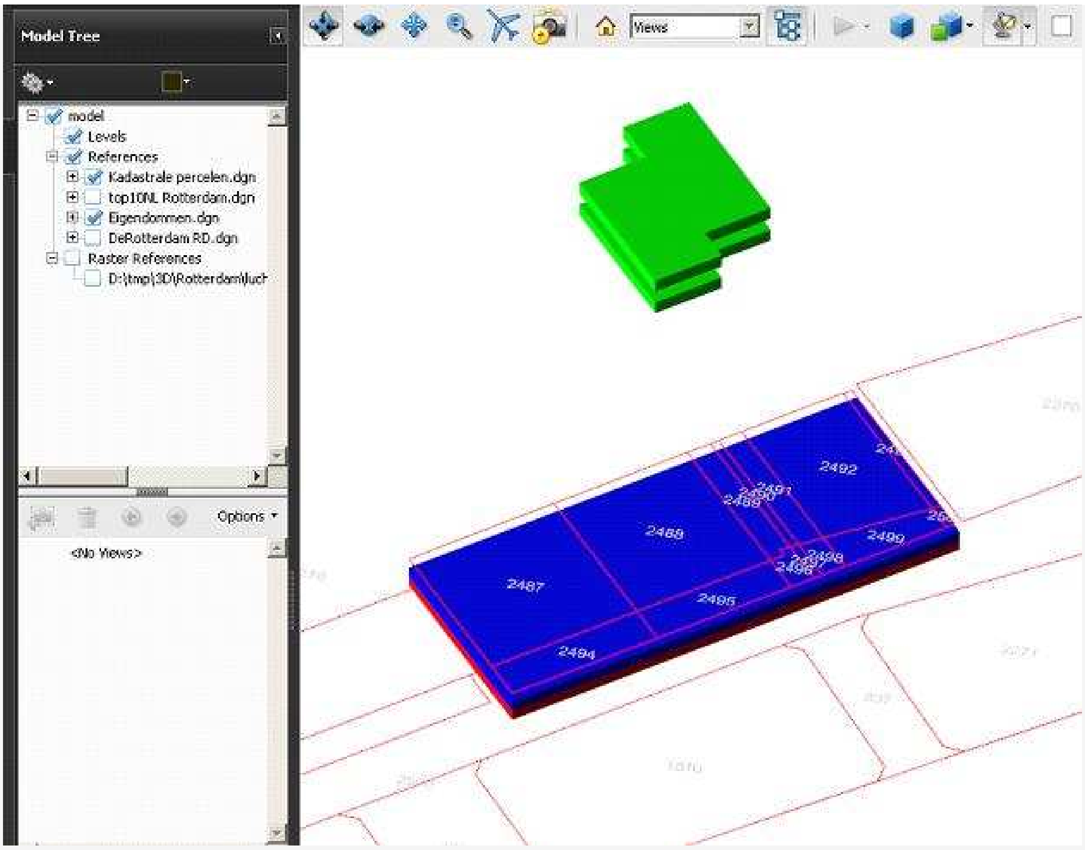
Figure 2. Examples of implementation in the City of Rotterdam (from the 3D Pilot project)



The 3D use cases focussed on a specific area in Rotterdam where 2D and 3D data were integrated (Figure 2). Use case demos are available on YouTube. At the closing symposium of the pilot the city of Rotterdam launched their 3D city model (CityGML) as open data (www.rotterdam.nl/ links_rotterdam_3d).

One of the use cases in the 3D pilot was a 3D cadastre test. Below an example of a 3D PDF from the '3D Pilot' project showing a possible 3D cadastral parcel (Figure 3). The nice aspect of 3D PDF is that it can integrate both the legal text and the associated drawing in one document, which is then submitted for registration of a transaction. With a standard Acrobat PDF reader, it is not only possible to see the text and a fixed impression of the 3D-drawing, but it is also possible to interact with the 3Ddrawing: rotating, scaling, slicing, selecting, etc. However, it is not possible to directly extract the 3D-geometry, for subsequent storage in the database.

Figure 3. 3D PDF example, from the Netherlands' 3D Pilot (by Kees van Prooijen, Bentley Systems)



The investigation into available data sets to create 3D-models allowed various organisations to make a contribution in the field where their strength lies, others were capable to develop procedures for 3D-reconstruction, or were involved in the test bed and use cases. The informal network type approach in the collaboration enhanced the value of the outcomes of the pilot, as well as the acceptability of the products by all those involved. Overall the pilot contributed to have focussed 3D ambitions and to a community-driven approach. In the follow-up further support to the implementation will be provided.

3.2 The ‘3D-cadastre modelling’ project in the Russian Federation

3.2.1 Legal aspects

The cadastre law in the Russian Federation is quite generic: it neither explicitly mentions 3D, nor does it prohibit 3D-parcels for registration. However, the current *Law on State Cadastre for Real Estate* offers a good foundation for development towards a 3D registration. First of all the Russian Cadastre not only registers (2D) parcels, but also cadastral (legal/register) objects that will have 3D characteristics such as buildings, apartment units, other constructions (like (underground) pipelines) and also buildings that are under construction. The so-called ‘Technical Plan’ contains information on the boundaries of those register objects. Although under the current law the Technical Plan does not contain 3D information as such, apart from floor plans in case of apartments, this manner of registration offers a good opportunity to develop towards an explicit 3D registration in future (Ploeger and Van Oosterom 2011).

Particular attention is paid to:

1. Measuring the overlap of 2D parcels with 3D object: 3D cadastral objects in Russia normally have a relationship with a physical object (building, tunnel, pipeline, etc.). It is not the intention in case of elongated under- or aboveground (3D) cadastral objects (for a tunnel or pipeline) to be split into several parts, as they traverse multiple land parcels.
2. Legal versus physical object: The model and its elaboration in the prototype will give explicit attention to legal vs. physical objects. The registration of legal items (cadastral parcels with rights) and their physical counterparts (buildings or tunnels) results in two different but related databases. This is already the case in 2D, but is even more in 3D. The display of physical objects for reference purposes: to show the location and size of the legal objects more clearly. (Van Oosterom and Zlatanova 2011).

5.2.2 Use cases in the Russian Federation

In this subsection a number of typical 3D use cases will be presented. Besides (2D) cadastral parcels and related administrative (legal) information, each case also includes terrain elevation, reference topographic data and 3D-models. The data for the selected 3D-cases are from Nizhegorodskaya Oblast, which has been selected as pilot region in this project. The following three different cases have been selected for the prototype:

1. Case 1 is the Teledom building (near the television tower) building, 9/1 ul. Belinsky. The building has interesting overhangs (possible above neighbour parcel with shops and also possible above public road/ footpath) (Figure 4).
2. Case 2 is the apartment complex at 66a Ulitsa Nevzorovykh. This case provides a more "normal" 3D configuration with property rights for 88 units for housing and 7 units for non-residential purposes (Figure 5).
3. Case 3 is a short underground gas pipeline of low pressure at Nizhniy Novgorod, Nizhegorodskiy district, from Piskunov str. to Verhnevolzhskaya naberezhnaya, 7 (Figure 6). The pipeline crosses land parcel with cadastral number 52:18:0060085:21, on which complex of museum buildings is located. Pipeline got two exits on surface (hatches), for which two (very small and hardly visible in the figure) land parcels are allotted 52:18:0060085:150 and 52:18:0060085:216.

Figure 4. Teledom building placed on DTM draped with topographic map for orientation

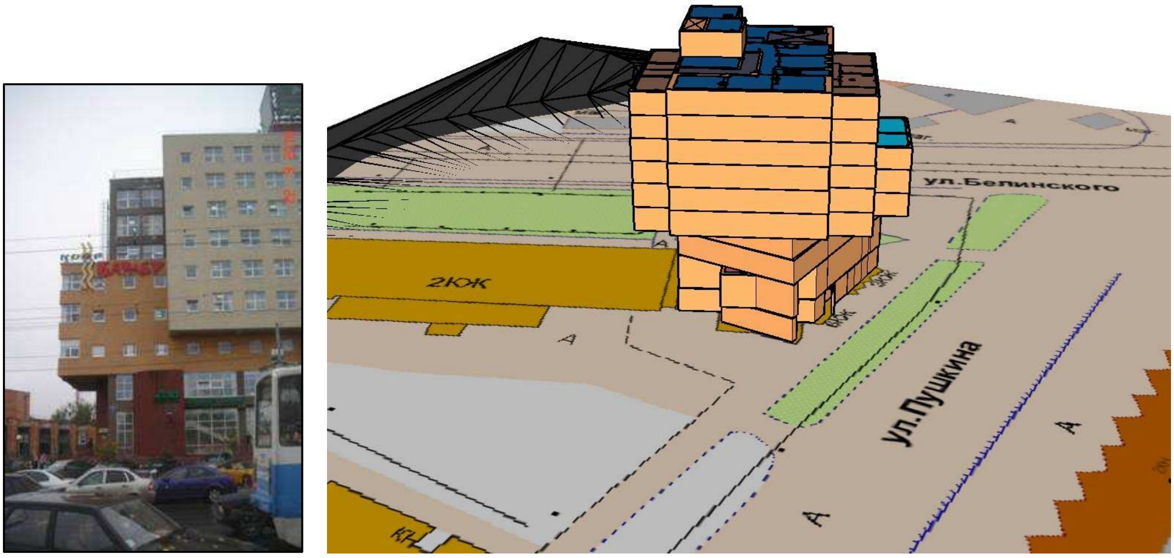


Figure 5. The apartment complex 66a Ulitsa Nevzorovykh

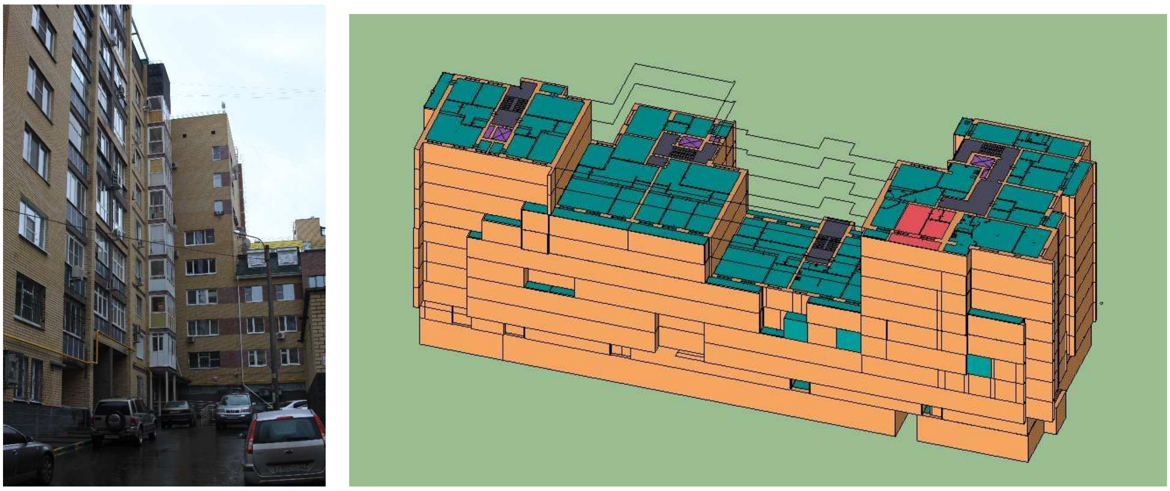


Figure 6. Top: Cadastral map fragment including the pipeline, bottom: two different 3D views

3.2.3 Technical aspects

The current cadastral parcel registration system is 2D polygon-based, in the terminology of the Land Administration Domain Model (ISO DIS 19152, 2011; www.iso.org). The database contains the full history of the parcel since its creation. The scale of the cadastral maps differs for pragmatic reasons from 1:2,000 in urban areas up to 1:10,000 in rural areas. The Russian Cadastre registers more than land parcels. According to article 1 of the Federal Law '*On State Cadastre for Real Estate*' the Russian cadastre (maintained by Rostreestr) registers five types of objects: (1) Land (parcels), (2) Buildings, (3) Apartment Units, (4) Other structures (bridges, pipelines etc.), and (5) Unfinished objects, i.e. objects under construction (buildings, bridges, pipelines, etc.). The implementation of this model, both the administrative (legal) and spatial parts, is realized via the two existing databases of Rosreestr: the 'Cadastre' database and 'Registration' database. The 'Registration' database does not contain geometry and is not affected by possible changes to support 3D cadastral objects (Vandysheva *et al.* 2011).

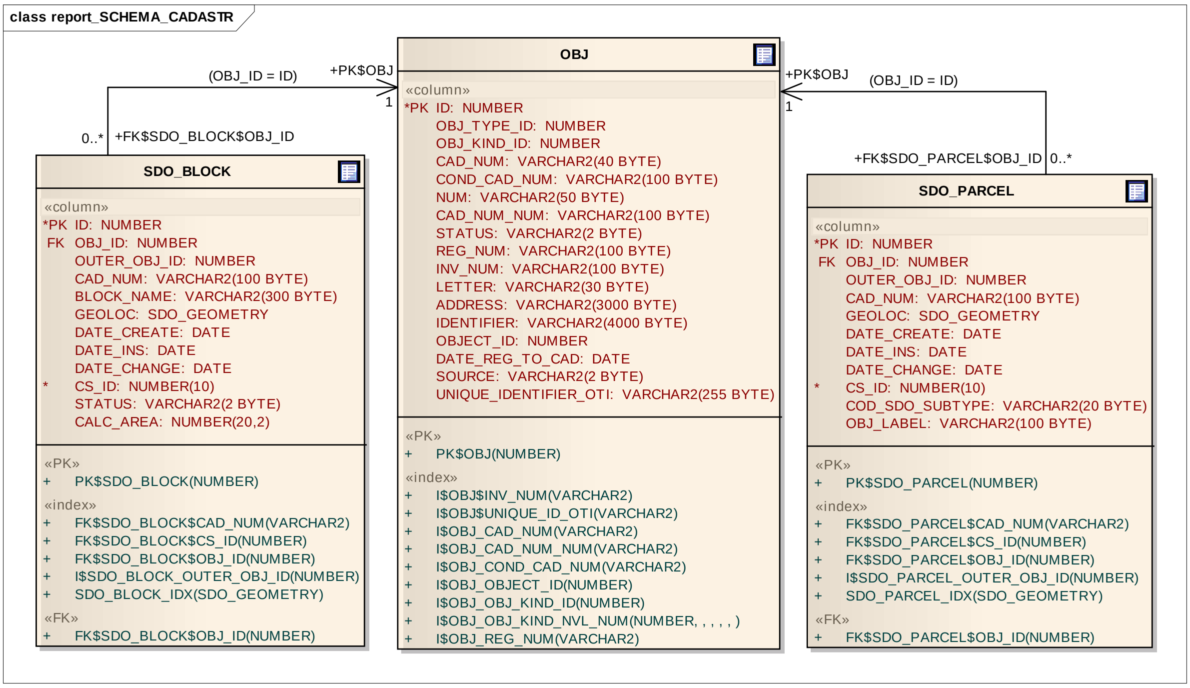
The design of the 3D Cadastral model is based on an analysis (of the geometric part) of the current cadastre registration (as in the first phase of the project it has become clear that there is no need to change the legal/administrative part of the model). As a reference model the ISO 19152 Draft International Standard (DIS) LADM was used. This already includes a 3D spatial profile. Based on the requirements derived from the potential use cases, it was decided that the 3D-registration is based on two objects:

1. 3D polyhedron volume (flat planes), or
2. 3D multi-curve with diameter (curved surfaces around pipelines).

A topologically structured 3D-cadastre is not the preferred solution as the current 2D Russian Land Registry also has no topology. The motivations in favour of the selected approach, besides that it does support the needs of the analysed cases, are that this approach is in line with the existing 2D-registration and should be relative easy to implement. The 3D volume parcels have their own geometry, similar as in the current 2D-database (via polygons). However, this time the geometry is represented by a polyhedron (volume bounded by flat faces) or multi-curve with diameter. So, the advantages are clear: relatively easy implementable with current technology (database, GIS/CAD), and similar to polygon approach in 2D. A drawback is that it does not support a topology structure (for better quality guarantees) and no curved faces. This means that during data entry careful checks have to be implemented to validate that 3D volume parcels are well formed and non-overlapping. Because curved faces are not supported (except via multi-curves with diameters for pipelines and cables), curved boundary surfaces need to be approximated by a series of flat surfaces. This is not a serious limitation and quite a practical and easy to implement solution.

The model is used for the specification of the rules for the initial registration of 3D-parcels, for the extended database schema, and for the dissemination and visualization of the 3D-parcels (in combination with the existing 2D-parcels) (Figure 7).

Figure 7. Part of the cadastre database (technical) model covering cadastre blocks and land parcels



The technical model will play an important role in the draft guidelines for the registration of new 3D-parcels. It is crucial to develop guidelines (possibly in the legislation on cadastre) describing how in the future in Russia, 3D-parcels must be submitted for registration. The proposed guidelines are based on experiences in other countries; especially the Queensland 'Directions for the Preparation of Plans'. Chapter 10 of these directions describes exactly how a volumetric parcel should be described so it can be registered. Based on this example and after analysing the cadastre in the Russian Federation, the guidelines are defined for the registration of new 3D parcels/cadastral objects (Vandysheva *et al.* 2011). The registration of a new 3D-parcel requires a 3D PDF document together with corresponding LADM/CityGML data. The actual encoding of the 3D-parcel (as part of the initial registration/survey plan) will be done in the XML standard format based on the integration of LADM-3D and CityGML (OGC standard for 3D city objects based on GML (XML encoding)). This solution allows explicit links between a 3D cadastral (i.e. legal) object (e.g. as in LA_LegalSpaceBuildingUnit LADM) and its physical counterpart (e.g. part of building CityGML). In the initial phase of the project, it is proposed not to include the explicit associations. Besides initial submission it must also possible in the future to submit changes via XML (CityGML) and refer to points with IDs. In the GML document the faces are defined by points encoded with <gml:pos> tags, and a point identifier can be included in the opening or closing tag; an example from the GML, version 3.2.1 standard (page 172):

```
<gml:pos>-34.9 140.1</gml:pos gml:id="p1" srsName="urn:x-ogc:def:crs:EPSG:6.6:4326">
```

Note that when a single new 3D-parcel that crosses multiple land parcels, this requires the transfer of the ownership (or other rights) of the involved 3D-spaces from the existing parcels to the single new 3D-parcel).

The preference is to store the 3D-parcels in the same database table as the 2D-parcels, so no database schema change is needed. However, an alternative option would be to introduce a new table for these 3D-objects. It is possible to derive from the 3D-geometry:

1. The 2D contour of intersection of 3D object with the surface z=0; and
2. The 2D projection contour of the 3D object on the surface z=0.

These 2D-contours (polygons) do not have to be submitted as they can be computed. The GEOLOC attribute (SDO_GEOMETRY) can contain multiple geometries. So, it is possible to store these derived 2D-polygons together with the 3D-polyhedron in a single GEOLOC attribute. It has to be decided whether these are computed on the fly or stored explicitly. In case they are stored, the preference would be to store multiple geometries in single SDO_GEOMETRY (again no database schema change). The new 3D-parcels have to be validated against the existing area's (2D-parcels) and earlier registered 3D-objects: are the rights properly transferred. The mentioned guidelines are intended for the initial registration.

The existing database schema of the Russian cadastre does not (or hardly) need to be adopted. In the legal/ administrative side there are no changes at all. But also because of the selected technical solution (polyhedron-based), there are also no (or hardly any) changes at the geometric side of the database. The 3D-polyhedrons do fit in Oracle spatial SDO_GEOMETRY type (as well as 2D polygons do). Oracle does call this a geometry subtype and the name for a polyhedron is a 'solid'. This is available since Oracle version 11. Perhaps one additional attribute could be added: 'diameter' (if larger or equal to 0 then this specifies the diameter of a 'multi-curve', if equal to -2 then this indicates a normal 2D-polygon, if equal to -3 the this is a normal 3D-polyhedron).

It is expected that spatial indexing (the R-tree in Oracle) could remain two dimensional (as the x- and y coordinates are by far the most selective). However, it may be of interest to investigate the performance effect of using a three-dimensional index, when large quantities of 3D-data are loaded in the database as in case of a dense urban area.

4. Conclusions and discussion

Developments in 3D-cadastre are triggered by the growing need to better manage our getting ever more complex environment and supported by the technological developments nowadays, including the decrease in costs of implementing 3D-solutions. Application of 3D has led to innovations and new insights in the Netherlands. From an attitude like "*3D is nice and promising, but I do not know how*" nowadays the pilot has assisted in "*focussed 3D ambitions*". Furthermore, the set-up of the pilot as a powerful informal network organisation (supported by social media) has created a flexible and highly motivated environment. As a result a 3D standard based on CityGML compliant with the international OGC standard and the national standard has evolved.

The aim of the '3D Cadastre Modelling in Russia' project, a cooperation by Russian and Dutch partners, is to provide guidance in the development of a prototype and to create favourable (legal and institutional) conditions for the introduction of 3D-cadastre in the Russian Federation. More specifically, a prototype is under development for the registration and retrieval of 3D cadastral objects from the pilot area Nizhegorodskaya Oblast. The project provides a unique opportunity to bring insights gained in various studies, such as the '3D Pilot' project in The Netherlands into practice and to achieve the optimal implementation of a 3D-cadastre for a specific national context.

The sharing of experiences and know-how between different organisations in the Netherlands and the Netherlands and the Russian Federation has quickened developments. Lessons learnt could be shared and immediately put into practice, thereby avoiding that every organisation or every country would have to go through the same pitfalls.

Acknowledgements

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