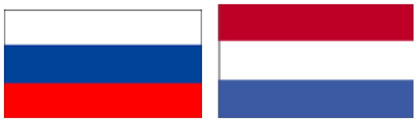

3D Cadastre Modelling in Russia
G2G10/RF/9/1 Report Work Package 2

3D-cadastral model for data generation, storage and distribution

Version
0.7 (8 nov’11)

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Report summary

This report documents the second work package of the G2G project '3D Cadastre Modelling in Russia'. The report presents the 3D-cadastral model for data generation (entry into the Cadastre), storage (in the databases of the Cadastre) and distribution (to users within and outside the Cadastre). The report starts with the analysis of three selected cases, followed by an overview of 3D models and formats (also used outside cadastral applications). The later provides an overview of possible options for the implementation of 3D cadastral objects. Next, this report presents the design of the conceptual model for the 3D cadastre (extension) in the Russian Federation, based the requirements as derived and described in the earlier report of WP 1 'Legal framework and organisation of 3D-cadastre'. Based on the options for representing 3D geo-information, the technical model for data entry (XML for data and PDF for documents) and storage (relational database schema) is given. Finally, the report concludes with the main findings of the second work package and summarizes the results.

Document Version Control

Version	Date	Content
0.0	2/05/2011	Peter van Oosterom, initial set-up.
0.1	27/05/2011-17/06/2011	Peter van Oosterom, various additional parts
0.2	18/06/2011	Sisi Zlatanova, chapter models/formats added
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0.4	21/06/2011	Peter van Oosterom, updated chapter 6 and Annex A
0.5	28/09/2011	Peter van Oosterom, comments from Russian partners included (12/08/2011) after translation by Veliko Penkov
0.6	24/10/2011	Veliko Penkov some last wording changes (due to translation); e.g. registration->recording
0.7	8/11/2011	Peter van Oosterom, some clarifications and minor formatting

3D-cadastre modelling in Russia

G2G10/RF/9/1

Report Work Package 2

Contents

1. Introduction, background

This report will present the on-going project on 3D cadastre modelling in the Russian Federation. The aim of this project is to provide guidance in the development of a prototype and to create favourable legal and institutional conditions for the introduction of 3D cadastre modelling in the Russian Federation based on experience of the Netherlands and other countries. After the initial analysis of the Russian legislation, inventory of possible use cases in Russia, and the examination of 3D Cadastre 'solutions' in other countries, the project is currently in the phase of the design of a 3D Cadastral model, which will then be followed by the development of a prototype system.

The Russian and Dutch partners in this government-to-government project are: Federal Service for State Registration, Cadastre and Mapping (Rosreestr), Federal Cadastre Centre (FCC) "Zemlya" and the Netherlands' Cadastre, Land Registry and Mapping Agency (Kadaster) in consortium with Delft University of Technology (TUD), Grontmij Nederland B.V., and Royal Haskoning B.V. Our analysis showed that the cadastral law in the Russian Federation is quite generic concerning 3D situations: it neither explicitly mentions 3D, nor does it prohibit 3D volumetric parcels for recording. Note that in this report we use the term 'registration' (and its synonym 'recording') for both spatial (e.g. parcel) and administrative (e.g. rights) information, There is a strong vision and drive in the Russian Federation towards a 3D cadastre for better registration of complex buildings, or other types of constructions, and (subsurface) networks; e.g., cables and pipelines. Since the start of the cadastral registration in the Russian Federation approximately 80 million parcels have been registered in 2D together with associated rights and restrictions (responsibilities) and the involved parties (persons). Therefore Rosreestr maintains probably the world's largest cadastre. On the website http://maps.rosreestr.ru/Portal/ both parcels and the legal and administrative information can be accessed online by the public; see Figures 1 and 2.

Because of the size of the Russian Federation several coordinate reference systems are used for accurate coordinates on cadastral maps (3 degree zones). In each region, special local coordinate systems are used for cadastral purposes. The parcels are described by polygons (and not based on a topological structure; see ISO DIS 19192. As polygons are more prone to topology errors, there are explicit rules to avoid overlap between parcels. The survey plans needed for the registration of new parcels are made by commercial companies.

Data maintenance is executed by the cadastre offices and data is managed in the databases of a number of regional offices (compared to the Netherlands this may mean that the area of a region is larger and sometimes also the number of inhabitants is larger). The software used countrywide comprises among others the following products: Oracle 9, ArcGIS and Panoramia (including the Russian coordinate transformations). Currently every few days data is copied to a central server for online web access to countrywide data (based on MapInfo's MapExtreme). From 2012 onwards it is foreseen that the updating will be executed on a daily basis resulting in real-time data.

Chapter 2 provides the analysis of three selected cases. A general overview of 3D models and formats is given in Chapter 3. The design of the conceptual model for the 3D cadastre (extension) is elaborated on in Chapter 4. The current databases within Rosreestr are introduced in Chapter 5 and provide the context for the technical model for 3D-extended data storage in Chapter 6. This chapter also provides the technical specifications for data entry: XML for data and PDF for documents. Finally, the report concludes in Chapter 7 with the main findings of the second work package '3D-cadastral model for data generation, storage and distribution.

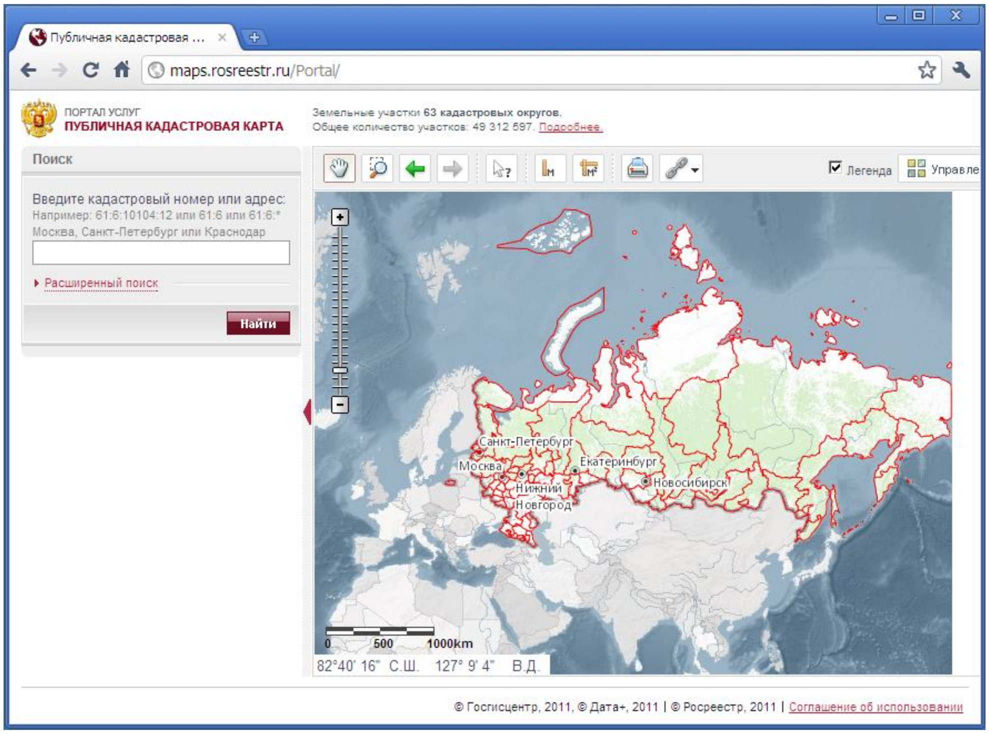

Figure 1: Overview of the on-line web.

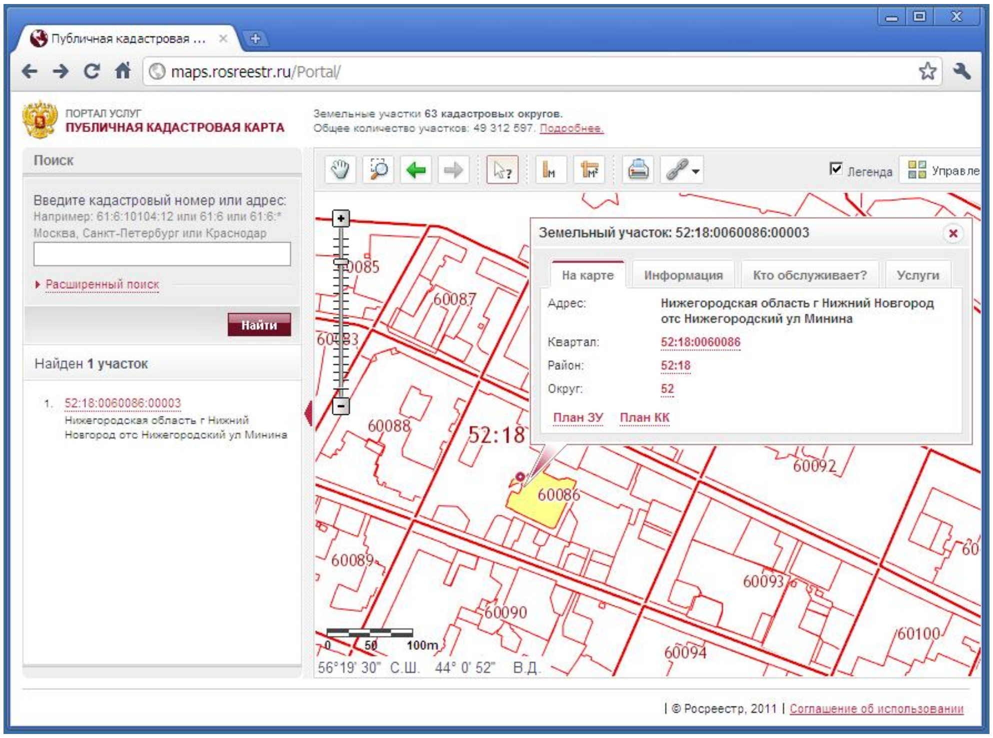

Figure 2: Detail of the on-line web portal, showing selected parcels and some administrative facts.

2. Selected typical 3D cases

For the project representative cases were selected of “3D-like" situations in the pilot area Nizhny Novgorod (Vandysheva et al, 2011). The office of Rosreestr in Nizhegorodskaya Oblast has selected the necessary test cases and will provide the appropriate data. The cases are analyzed in order to:

1. understand the current registration (2D).
2. understand both the spatial and legal / administrative side of the registration.
3. formulate specifications for future 3D recording.
4. create initial guidelines for recording of 3D objects.

For the analysis of the cases textual descriptions, photos, legal documents and maps are available. In addition, information will be collected in the field to get better understanding. There are roughly two types of cases were selected: 1. complex 3D situations, which are uncommon, but much to gain from a real 3D recording (and not a 2D recording), and 2. 3D normal situations, such as apartments, which are very common and also benefit from a 3D registration. The three cases that are presented below will also be used in the sequel of the project, that is the prototype for the pilot (two other earlier suggested cases will not be used further). In the sequel of the project also (at least) two new 3D cases will be added, in order to have a total of five representative cases.

2.1 Case 1

Teledom building (near the television tower) building, 9 / 1 ul. Belinsky: This is an ‘older’ type of registration in technical building database including the floor plans. The rights of the various units are individually recorded in the rights register. The building has subsurface parts and above air overhangs. With the ‘older’ registration approach, the floors are either in DWG format or scanned images (roughly ‘geo-referenced’ by cadastral block or street address, not yet via parcel level). The basement (for underground parking) and first 2 floors are owned by a bank. Second owner has above this a multi-floor column (same part at every floor) and leases the different units (floors) to different users. If lease in Russia is longer than one year, then also the lease needs to be registered. In total there are 20 units in the building, with 10 different owners. The building has interesting overhangs (possible above neighbour parcel with shops and also possible above public road/ footpath). Because of the interesting 3D configuration of legal spaces, this is a very good case to be further used in the prototype (see Figure 3).

Figure 3. Impression Teledom building.

2.2 Case 2

Apartment complex, 66a Ulitsa Nevzorovykh. This case provides a more "normal" 3D configuration with property rights for 89 units for housing and 7 units for non-residential purposes. The underground car park is jointly owned. There are 6 registered mortgages on residential units. The land parcel is jointly owned. Figure 4 gives an impression of the situation.

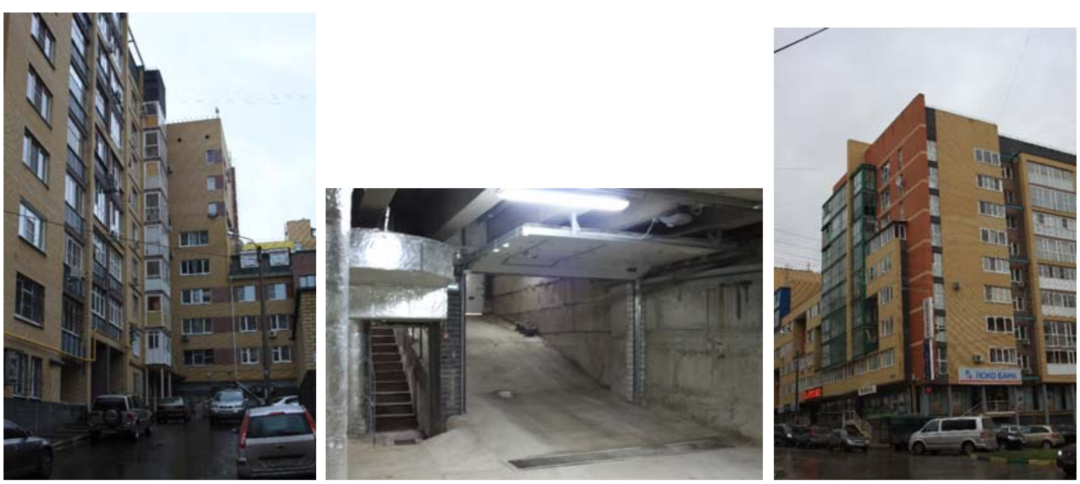

Figure 4. Impression Apartment complex, 66th Ulitsa Nevzorovykh.

2.3 Case 3

A short underground gas pipeline of low pressure, located at the address: Nizhniy Novgorod, Nizhegorodskiy district, from Piskunov str. to Verhnevolzhskaya naberezhnaya, 7 (see Figures 5, 6 and 7 for an impression).

The object properties are:

- Conditional registration number of the pipeline -52-52-01/754/2009-130;
- Pipeline length - 72,73 m;
- Pipeline diameter - 50 mm;
- The object got one owner - Nizhegorodoblgaz Co;
- 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 land parcels are allotted 52:18:0060085:150 and 52:18:0060085:216.

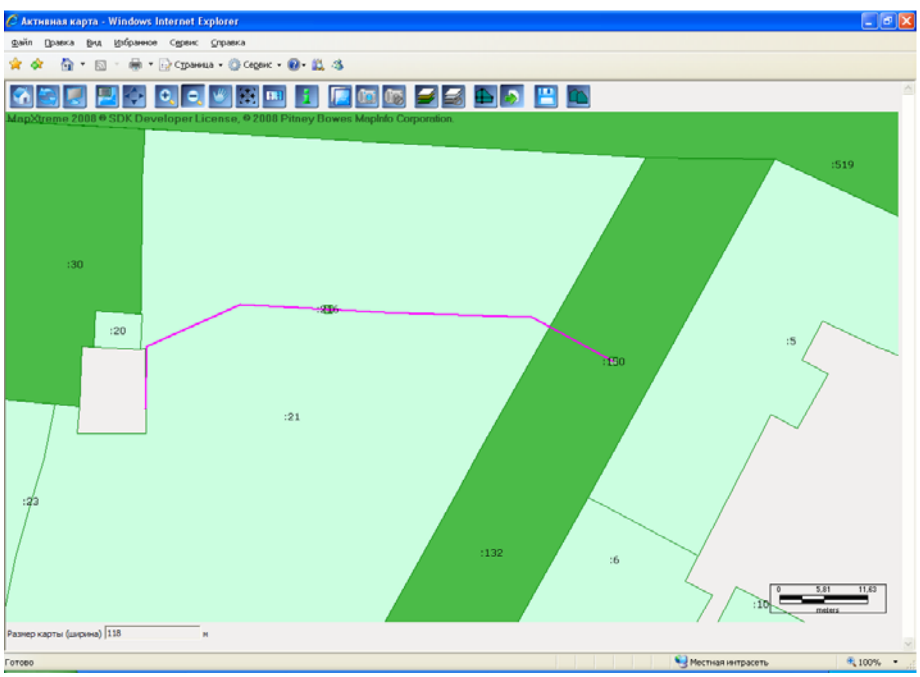

Figure 5. Cadastral map fragment: the pipeline.

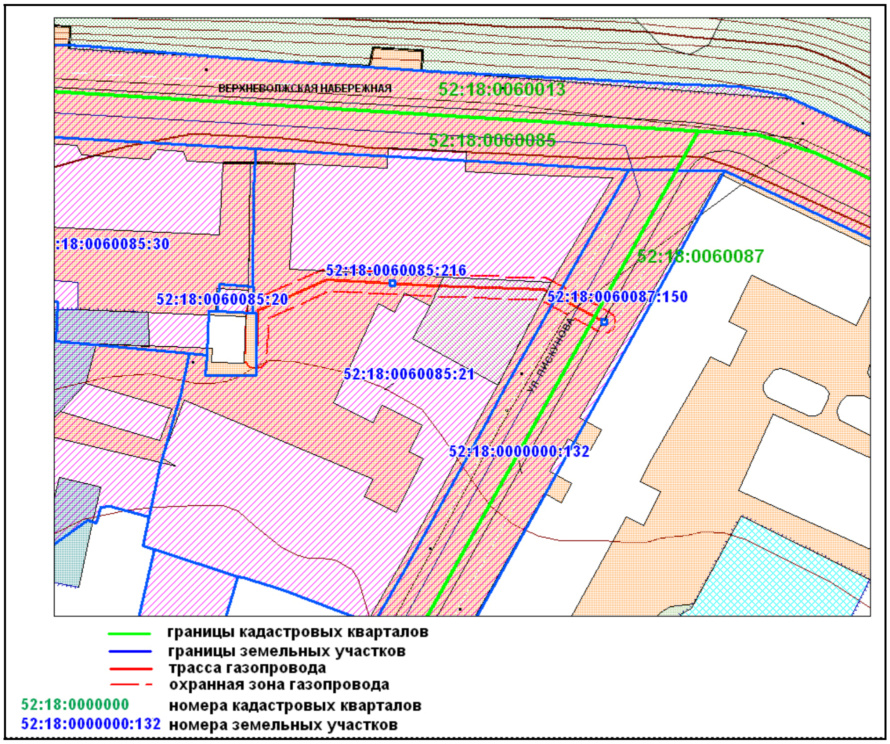

Figure 6. Gas pipeline on topographical map with scale 1:2 000, with borders of cadastral blocks and land parcels

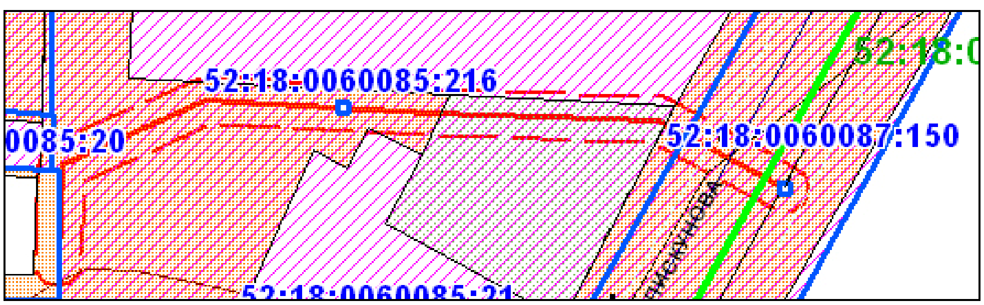

Figure 7. Land parcel 150 and 216 with pipeline hatches (Zoomed fragment)

2.4 Conclusion of analysis use cases

An initial analysis of the cases offers an indication about the scope of the proposed 3D cadastre in Russia. These insights will be developed in the remaining part of the project:

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.

3. Overview of 3D models and formats

This section gives a short overview on approaches for 3D modeling, and 3D standards (models) that are mostly used by software vendors. The section concludes with a comparison between the well-used standards. This comparison is used as a basis for the technical model in section 5

3.1 Approaches for 3D representations

In the literature, two major 3D abstractions are distinguished for modelling 3D objects and phenomena (Mäntylä, 1988, Latuada 2006): Surface-based and Volume-based (see Figure 8, left). Constructive Solid Geometry (CSG) and Boundary representation are typical examples of Surface-based representations, while voxel (regular space subdivision) is an example of volume-based representations. All approaches have advantages and disadvantages considering different criteria and depending on the specific application.

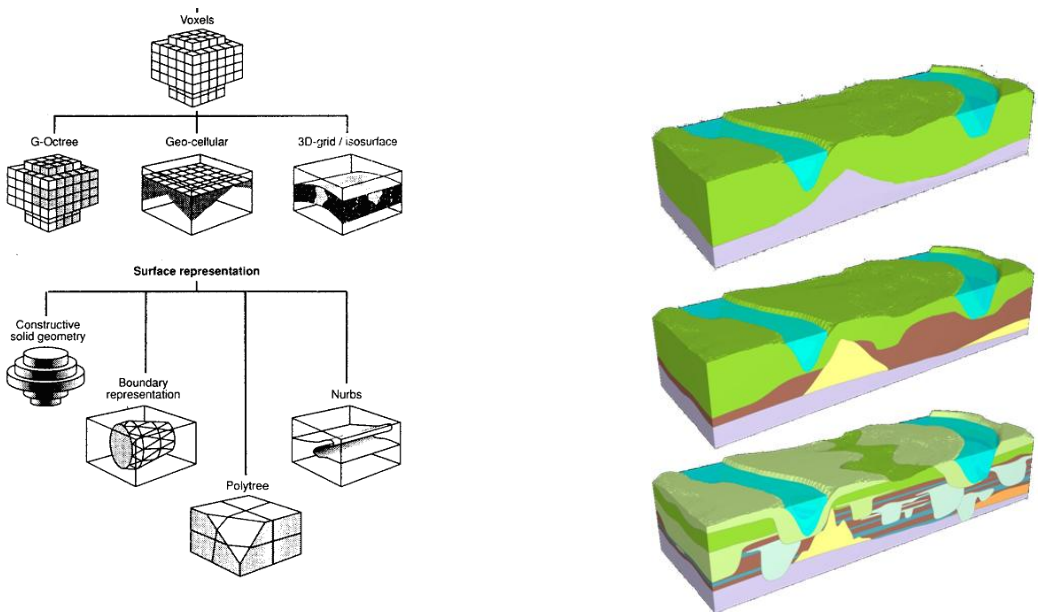

Figure 8: left, 3D spatial representations (courtesy Lattuada 2006) and right, a voxel model with different voxel sizes (TNO, Netherlands).

A voxel is a regular 3D volume element, i.e. 3D 'pixel'. A 3D object is then represented as an array of voxels. Each voxel holds one (or more) data values. Voxel representation is appropriate for modelling of continues phenomena such as geology, soil etc (Figure 8, right). The benefit of voxels is that they are regular in modelling and thus easy for management and analysis (i.e. the volume is very easy to compute). A disadvantage of voxels is that high resolution data result in large volumes of data. Furthermore, the surface is always somehow "rough", which might result in unrealistic visualisations. In contrast to the regular voxel, Constructive Solid Geometry (CSG) uses spheres, cubes, and cylinders as basic primitives. Set operations (union, intersect, difference) are applied to the basic primitives to construct 3D bodies. The advantages of CSG that they are good in computer-aided manufacturing: a brick with a hole drilled through it is represented as "just that". The disadvantages for real world modelling are that the objects and their relationships might become very complex.

Boundary representation is the approach that is widely accepted for modelling of discrete real-world objects (Foley, 1995). The 3D object is represented by bounding low-dimensional primitives (vertex (0D), line (1D), polygon (2D), polyhedron (3D)), which are organised in data structures. The primitives can be either simple such as planar faces and straight edges or complex such as curved surfaces and edges. The main advantage of boundary representations is that it represents real-world objects as they are perceived by humans. The boundary of the objects can be obtained by measuring properties that are visible (i.e. "boundaries"). Moreover the rendering engines are also based on boundary representations (i.e. triangles). However, the complexity of 3D boundary representations is high and no unique data structure exists. For example in 3D a boundary primitive could be a face (topologically described), a triangle or a polygon (geometrically described), with constraints such as planarity, number of points and arcs, the order of edges and nodes, relation with neighbours etc. Constraints are even more complex, e.g. how to determine neighbours in 3D, how to ensure planarity of faces in 3D. Furthermore, the rules for a valid 3D primitive may differ as well.

Although more complex, boundary representation is in the basis of most the file formats (models) used in GIS and CAD used for exchange of information and is also quite suitable for 3D cadastre applications.

3.2 3D file formats

A diversity of file formats exists for exchange of 3D data. Some of them have been developed as standards by international organizations (VRML, X3D, IFC, CityGML), others have been developed by vendors but due to the wide use are accepted as standards (KML) and a third group of standards have become de-facto standards due to their wide acceptance by users and software vendors (SHP, DXF, COLLADA, 3D PDF). The file formats are created to serve a specific goal (i.e. SHP to have geometry and attributes), VRML (to allow realistic visualization and interaction), COLLADA (to support modelling), IFC (to keep semantics next to geometries), etc., and therefore have different characteristics. Some of the most well-know file formats will be shortly reviewed below.

DXF (Drawing Interchange Format) has been created by Autodesk, first version dates back to December 1982 as part of AutoCAD 1.0 and has grown through the years as one of the most used formats for exchange of 2D and 3D CAD drawings. The file structure is ACSII-based and well described. Specifications for DXF from AutoCAD Release 13 (November 1994) to AutoCAD 2008 (March 2007) are available on the web site of AutoDesk. The file formats supports many different geometries (simple and complex), layers and drawing attributes. Since it has been designed as drawing Interchange format, is does not does not support thematic attributes. Except some AutoDesk specific viewers, there is no web-based viewer, i.e. the files format is used only to exchange data from one software package to another. Topology, texture, objects, level-of-details are not explicitly supported, although the user can apply some tricks.

The shapefile (SHP) is created by the Environmental System Research Institute (ESRI Inc.), was first released in 1998 and is a typical example of a GIS file format. It supports simple geometry (i.e. OGC point, multi-point, polygon, polyline and since ArcGIS 10 polyhedron) but also a vendor specific data types (i.e. multi-patches). SHP is binary file format and adapted for faster drawing speed and editing capabilities. The major advantage of this file format is that the objects are kept with their thematic attributes. The file format consists of three files: main file: *.shp; index file: *.shx and DBase file: *.dbf. Shapefile is the most used format for GIS data. There are many tools and applications that can read and export SHP file. SHP does not have a topological structure and the representation of textures is very basic.

The Virtual Reality Markup Language (VRML) was first released in 1995 and accepted as a standard by the Web 3D consortium. It was designed as a web standard for exchange of graphics and giving possibilities for interaction with 3D world. Practically it is a language for modelling 3D realistic scenes and interaction. Figure 9 illustrates the syntax of the file, with the characteristic property that it starts with a list of nodes and is then followed by a list of faces (referring to the earlier nodes).

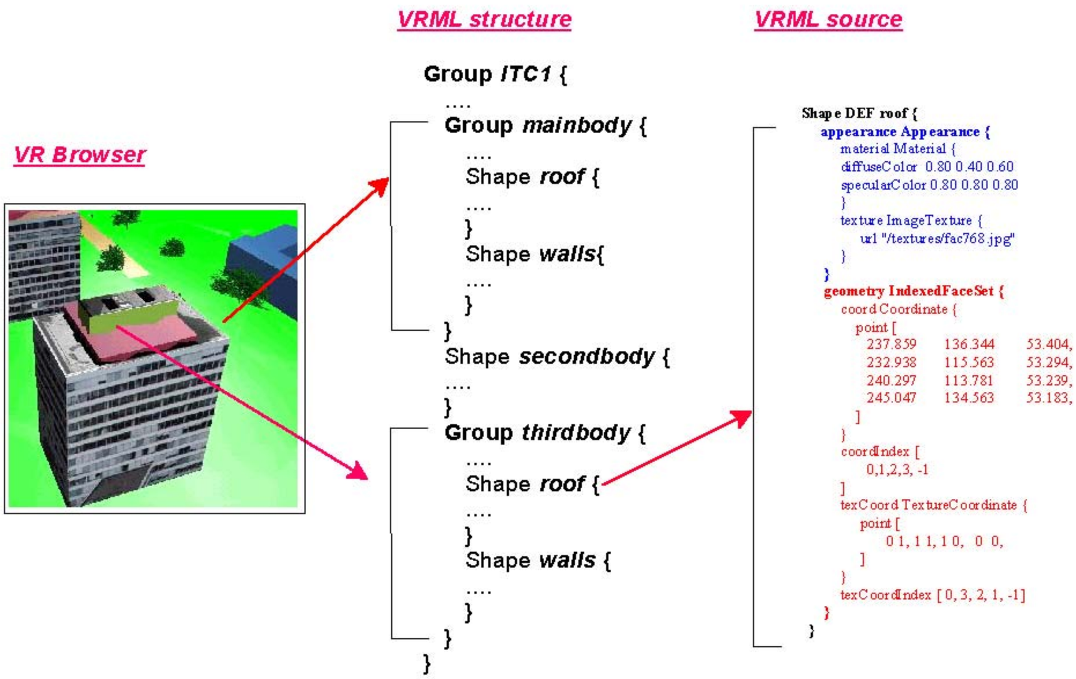

Figure 9: Example of a VRML file format.

As it can be seen it is possible to define objects (their semantics) and even to attach attributes. The file offers several texturing mechanisms and a variety of different geometries. Good visualisation performance can be obtained when using binary representations (i.e. gzip), but simple visualisations look 'too schematic'. This was one of the major reasons for rather limited use of VRML for real world projects. Taking into account some of the disadvantages of VRML (not XML-based, large models result in large files, etc), the Web 3D consortium has stopped the development of VRML after 1998 and concentrated on the XML based X3D file format. This XML file format is an improvement of VRML but this file format is currently even less used than VRML. Only a few viewers are available for visualisation of data on Internet and almost no vendor supports export and import of X3D. Some experts suggest that the file became too complex (and the XML encoding is even more verbose that the ASCII encoding).

An example of very simple standard that was quickly accepted by users and software vendors is Keyhole Markup Language (KML). It is developed by the company Keyhole (bought by Google) and brought by Google into OGC standard suite. The goal of the format is straightforward: to represent geographic features and annotations (geographic coordinates). It is intended for web-based online maps (2D) and digital globes (3D). The focus is explicitly on visualization and user interaction. Semantics, topology, LOD are not supported; simple attributes can be attached to the objects. Collada (KRONOS Goup) is often seen as a 'better' version of KML. It is a generic, extensible format for 3D content creation and does offer much more properties and functionality. It offers a very good representation of 3D geometry and appearance (and since V1.4 support of topology), very good appearance and physics models (shaders, animation, ragdolls) and geo-referencing (since V1.4). Being supported by GoogleMaps and Google Earth, these two standards became extremely popular in a very short period of time. Most of the CAD and GIS vendors offer export of 3D models in KML. However as the target visualization environment is mostly Google, these file formats are not appropriate for visualization of underground objects.

A very interesting development is the 3D PDF. The intention of this file format is to publish and share 3D design information within a normal PDF file format. Several Large CAD vendors (Bentley Systems, Autodesk) allow export to this file format. The 3D geometry is exported in a PDF format and can be integrated in the modelling environment of Adobe into the textual (including static images) document. The 3D model can be the explored in the standard Acrobat reader by a tool box for 3D interaction (developed by Bentley Systems). It is also possible to run animations, add comments, etc. If not digitally viewed, the document can be printed. Then the 3D model appears as picture.

CityGML is the newest standard (OGC, 2008) for representing of 3D real-world information. CityGML is an object-oriented model that allows semantic, geometry, topology and appearance characteristics to be stored per object. The semantics is expressed by classes, which aim to cover a large group of commonly used real-world objects. There are 8 classes as specified in Figure 10. Additionally to these core classes there are classes for appearance, and generics. Generics class is used to extend the model with new objects (not defined by the core; e.g. 3D cadastral parcels) and attributes.

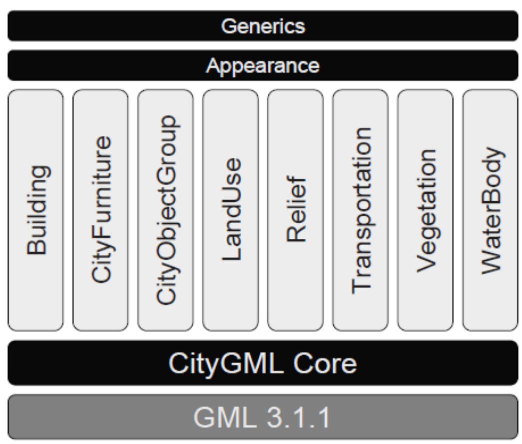

Figure 10: Classes in CityGML 1.0.0.

Another mechanism to describe new objects in CityGML is by creating an Application Domain Extension (ADE). This mechanism is more powerful since it allows new objects to be defined with their semantic, geometry, appearance and topology properties. Several extensions are already provided: Noise (for noise analysis), tunnel, Bridge, GeoBIM (detailed information from BIM/IFC), Facility management (CAFM), Hydro (for flood analysis) and Utility networks. Discussions are going on extension for geology and geo-technology. An ADE for indoor navigation, i.e. objects and their attributes that are specifically important for indoor routing, is also under development.

The model is based on GML3.1.1 and as such all the geometry of GML are inherited by the semantic extension. GML supports 0D to 3D primitives (point, curve, surface and solid) and supports composition objects. A very useful geometry in this respect is CompositSurface, which is a set of connected surfaces. Almost all 3D objects (buildings, city furniture, water body) are represented by *CompositeSurface* geometry. *CompositeSurface* can be mapped with textures (artificial or photrealistic). Optionally the objects can be represented as *Solid*. *Solids* must be watertight and the software that creates the CityGML file has to ensure this property.

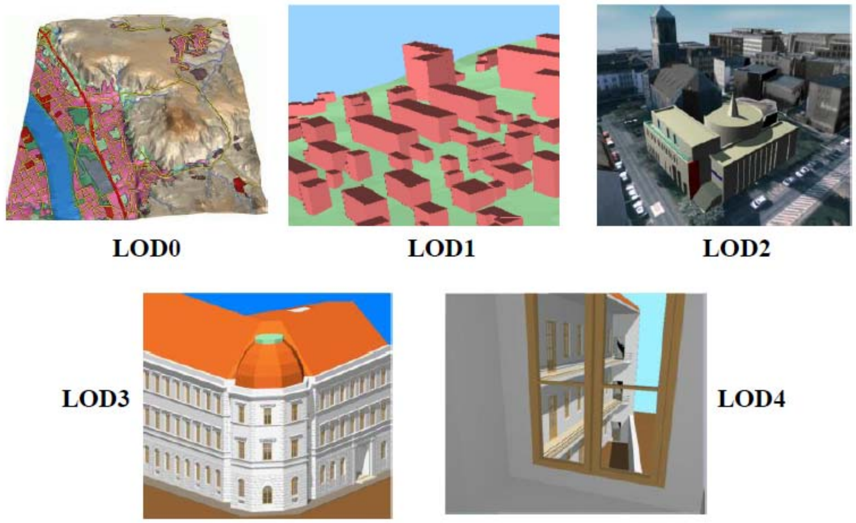

Figure 11. CityGML LOD for buildings (CityGML).

CityGML supports 5 different levels of details. The most prominent are the LOD of buildings (see Figure 11). Buildings have 4 LOD starting from LOD1 to LOD4 (indoor). The CityGML idea of LOD differs significantly from the well-known LODs of computer graphics. CityGML LODs represent a specific resolution of real-world objects that might be of interest for a specific application. For example, an application to determine the coverage of telecommunication antennas, will only need simple extrusion boxes (e.g. LOD1), while an urban planning application will require models with well-represented facades, roofs, etc. The LODs are not per se intended to support fast visualisation (as this is the case in computer graphics), although they have been used. LODs are intended to represent the accuracy of the objects, i.e. LOD0 has the lowest resolution (few meters) and LOD4 the highest (few millimetres). LOD0 is a 2,5D model and represent only surface objects. LOD4 for buildings is the first well-structured GIS representation of indoor environments. In contrast to Building Information Models (BIM), it offers indoor representation that reflects the human vision on buildings, i.e. the buildings consists of rooms and the rooms have doors, windows and furniture.

CityGML conceptual model exists currently in two implementations as GML file and spatial schema for DBMS. CityGML file export is supported or going to be supported by several vendors such as Safe software, Autodesk, ESRI, Bentley Systems. Some companies (e.g. Bentley Systems, Autodesk) and Universities (e.g. TU Berlin, TU Delft) have experimented with database implementations of CityGML.TUBerlin has dveloped 3DCityDB for Oracle Spatial. The spatial schema follows closely the conceptual model and uses the Oracle Spatial geometry data types. An import export application for this data base is also available. The application reads CityGML files and populates the database. Export is possible in CityGML and KML files. CityGML is being increasingly used in various countries all over the world. A lot of attention was also given to CityGML in the Netherlands. A 3D pilot was initiated by three national organisations: Kadaster (the Dutch national cadastre and mapping agency), Geonovum (the National Spatial Data Infrastructure executive committee) and the Netherlands Geodetic Commission (co-ordinates and initiates fundamental and strategic research in geodesy and geo-information in the Netherlands). Four major activities were defined and executed:

1. Identifying the availability of 3D geo-data and geo-information and sourcing test data as well as identifying best practices for 3D geo-information acquisition
2. Investigating and defining 3D standard-NL
3. Designing and implementing 3D testbed
4. Specifying needs for 3D geo-information and technologies through use cases and evaluation of prototypes

The major result of the project is the suggestion to extend the 2D base topographic map of Netherlands to 3D following the CityGML concept. More information about the project can be found in Verbree et al 2010 and Stoter et al 2010. The standards mentioned above are compared according to 11 criteria. The comparison study was completed during the work of WG2 of the above mentioned 3D pilot of the Netherlands.

Table 1. Comparison between 3D exchange standards (created within WG 2 Standards of the 3D pilot).

	DXF	SHP	VRML	X3D	KML	Collada	IFC	CityGML	3D PDF
Geometry	++	+	++	++	+	++	++	+	++
Topology	-	-	0	0	-	+	+	+	-
Texture	-	0	++	++	0	++	-	+	+
LOD	-	-	+	+	-	-	-	+	-
Objects	0	+	+	+	-	-	+	+	+
Semantic	+	+	0	0	0	0	++	++	+
Attributes	-	+	0	0	0	-	+	+	+
XML based	-	-	-	+	-	-	+	+	-
Web	-	-	+	++	++	+	-	+	0
Georef.	+	+	-	+	+	-	-	+	+
Acceptance	++	++	++	0	++	+	0	+	++

- not supported; 0 basic; + supported; ++ extended

The criterion *geometry* estimates the support of 3D geometries. Standards that support only the simple features (point, line, surface and eventually polyhedron) are classified as giving support to 3D features. Standards that allow use of parametric shapes (cylinders, spheres, etc.), freeform curves and surfaces, sweep representations, etc. are considered to have 'extended' support.

Topology evaluates the existence of relationships between the geometries in the model. The basic support means that very simple relationships are stored. For example a 3D object in VRML and X3D is represented by two lists of: 1) all the nodes in the object and 2) polygons which use the sequential number of the nodes (thus no duplication of nodes). IFC does not have a topology in terms of neighbourhood relationships but it can be derived from the maintained containment relations. CityGML theoretically supports a topological data structure as specified by OGC but no model so far has been created using this topology.

Texture evaluates the support of texturing with real photos. Standards that support texture mapping (geo-referencing between images and geometry) are classified as 'supported'. Standards have extended texture possibilities if they allow both texture mapping and texture draping.

Levels of Detail (LOD) is indication for support of several geometries for a single object. In the case of VRML and X3D this is for visualisation (the browsers use them to speed up the visualisation). In the case of CityGML they are used to indicate the resolution (a bit like a scale) an object is represented. Most browsers do not use them in the visualisation (in case of multiple LODs some browsers visualise all of them).

Objects criterion estimates the possibility to distinguish between different objects in terms of geometry. DXF is layer-based, but have some basic tools to group geometries to indicate that this is one entity within a layer. Using KML and Collada the user should pay a lot of attention on the creation of the file to be able to recognise different objects. The best way to keep track of objects is to create separate files. Therefore these two standards are indicated as not supporting objects.

Semantics indicate the possibility to assign thematic meaning to an object or a group of objects. Using DXF, SHP and 3D PDF this is possible to be done by the names of the layers. Much information about an object can included as text in the PDF file. IFC and CityGML are considered to have extended possibilities because the classes are well-defined in advance. All other standards allow some basic tricks to get thematic information attached to geometries (by anchors, annotations, etc.)

Attributes estimates the possibility to incorporate thematic attributes in the standard. The most elaborated concept is the SHP standard (in combination with the database file). However, IFC and CityGML have standard well-defined attributes per object. The attributes of the object in 3D PDF can be listed in the document part next to the 3D geometry.

The criterion *XML* indicates whether the standard is XML-based.

Web criterion gives an indication which standards are designed and optimised for Web use. X3D is actually an improved version of VRML. KML (once loaded) has better performance than the current CityGML browsers. Large 3D models create big 3D PDF file therefore this standard is a bit lower ranked.

Geo-referencing estimates the possibility to use geographical coordinates. It should be noticed that there is a version of VRML, i.e. Geo-VRML, which works with geographical coordinates. There are discussions on how to incorporate geographical coordinates in IFC.

Acceptance indicates the support of the standard by software vendors.

4. Design of the conceptual model

4.1 Current cadastral object types

The current cadastral parcel registration system is 2D polygon based (ISO DIS 19152, 2011), implying that the boundary between two neighbouring parcels is repeated (this in contrast to a topology based representation where the common boundary is only represented once). In the polygon based approach each parcel does have its complete list of coordinates (and neighbours repeat the shared coordinates). These replications might be the source of mistakes, such as incorrect overlap of neighbours in slivers. Therefore, there are rules to avoid overlap between parcels. The database contains the full history of the polygon 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 (see Figure 12): 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.)

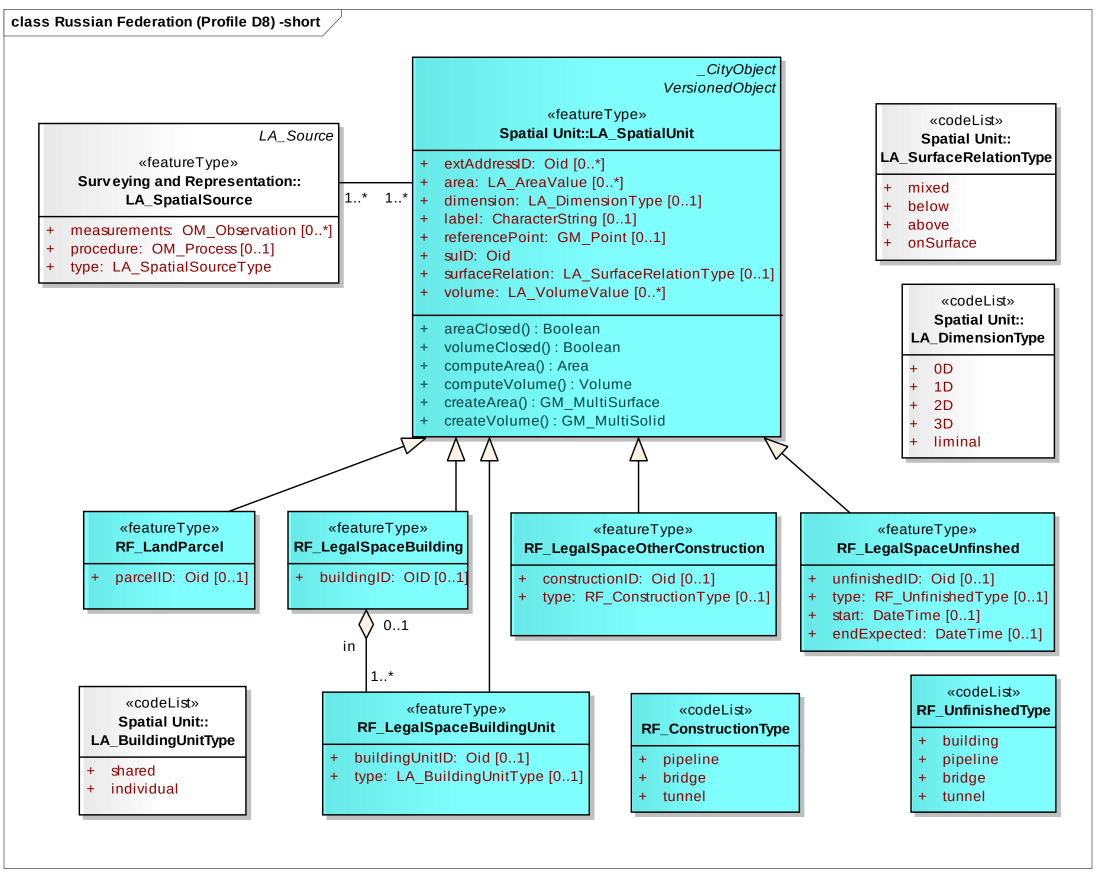

Figure 12. The initial Land Administration Domain Model (LADM) profile for the 3D cadastre pilot project in the Russian Federation, with five different types of cadastral objects (LA_SpatialUnits LADM in terminology).

4.2 3D Cadastre extension

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) Land Administration Domain Model (LADM) has been used and this is quite convenient as this already includes a 3D spatial profile.

In the report of WP 1, we presented and analysed five options for the Russian 3D-Cadastre: 1. Minimalistic 3D cadastre, 2. Topographic 3D cadastre, 3. Polyhedral Legal 3D cadastre, 4. Non-polyhedral Legal 3D cadastre, and 5. Topological Legal 3D cadastre. Based on the requirements (derived from the potential use cases), option 3 (legally 3D Land Registry based on polyhedron volume objects, flat planes) was the selected approach. This in combination with a modest version of option 4 for volumes with curved surfaces around pipelines or cables (multi-polyline with diameter). Option 1, the minimalist approach to 3D Land Registry does not solve the sometimes complex 3D situations. Option 2, topographical 3D cadastre (3D parcels define referrals of 3D physical objects), is not conform to the current 2D Land Registry which is based on properties with own geometry. And Option 5, a topologically structured 3D Cadastre, is not conform to the current 2D Russian Land Registry, which has no topology. The motivations in favour of option 3, besides that it does support the needs of the analyzed cases (Chapter 2), 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 bound by flat faces). 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 for data validation: well formed and non-overlapping 3D volume parcels. Not supporting curved faces (except via polylines and diameters for pipelines and cables), means that 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); see chapter 6.

5. Current Russian databases

Before discussing the storage of 3D cadastral object in the database, first a shot overview is given of the two existing databases of Rosreestr: the ‘Cadastre’ database (Schema_Cadastr) and ‘Registration’ database (Schema_Right). Table 2 shows relationships between the most important tables in both databases and the LADM (as reference model). Note that for a more clear presentation not all the tables are shown. The ‘Registration’ database does not contain geometry and is not affected by possible changes to support 3D cadastral objects. Table 3 lists the tables which are important for the geographic representation and Figure 13 shows a part of the technical model (tables) of Cadastre database covering cadastre blocks and land parcels. Some data content of these two tables are shown in Figures 14 and 15. The geometry attribute in the SDO_ tables is called GEOLOC and uses the Oracle spatial data type SDO_GEOMTERY.

Table 2. Relationship between LADM concepts and the tables in the Cadastre and Registration databases of Rosreestr (provided by Sergey Pakhomov).

LADM entity	Describing Tables	
	Schema_Cadastr	Schema_Right
LA_BAUnit	Obj,Reg	Oni_List
LA_Party	Right_Owner_*,Encumbrance_Owner_*	JRDP_List,PRSNF_List
LA_RRR	Right,Encumbrance	EGRP_*
LA_SpatialUnit	Entity_Spatial	-
LA_AdministrativeSource	Doc	EGRP_DocBS
LA_Source	EDoc_Info	-

Table 3. Overview of tables in the Cadastre database, which are relevant for geographic information (provided by Sergey Pakhomov).

Table	Comments
OBJ	Basic information on the object
Entity_Spatial	Description of the spatial component of object
SDO_District	Cadastre rayon
SDO_Block	Cadastre block
SDO_Parcel	Land parcel
SDO_OKS	Object of construction
Coord_System	Reference system description

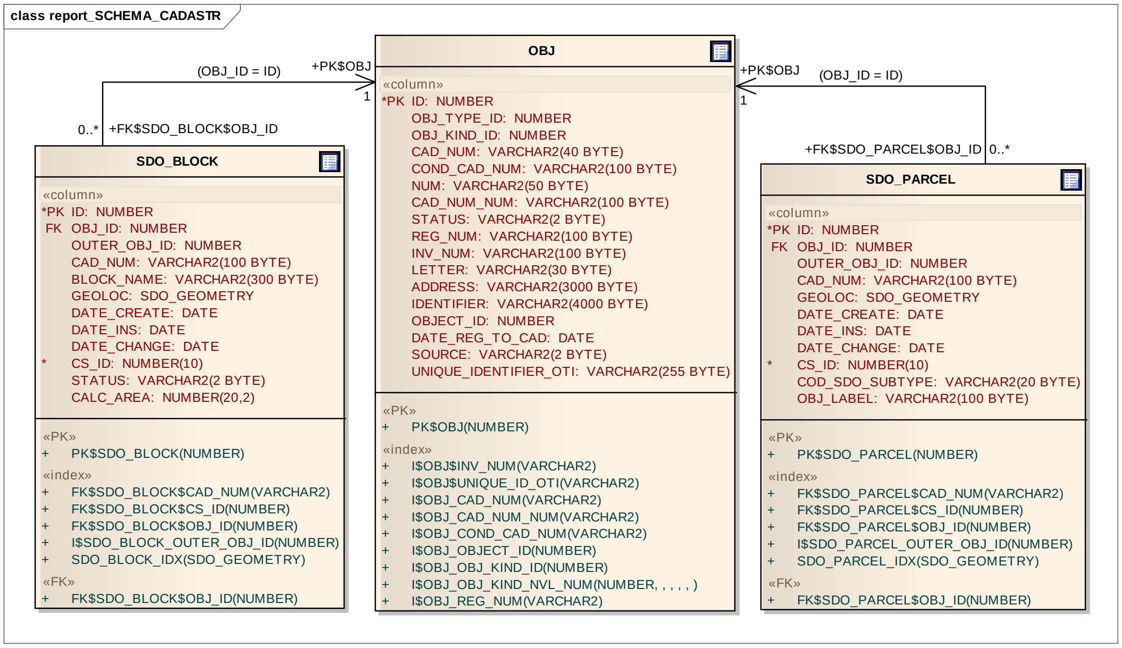

Figure 13. Part of the Cadastre database (technical) model covering cadastre blocks and land parcels.

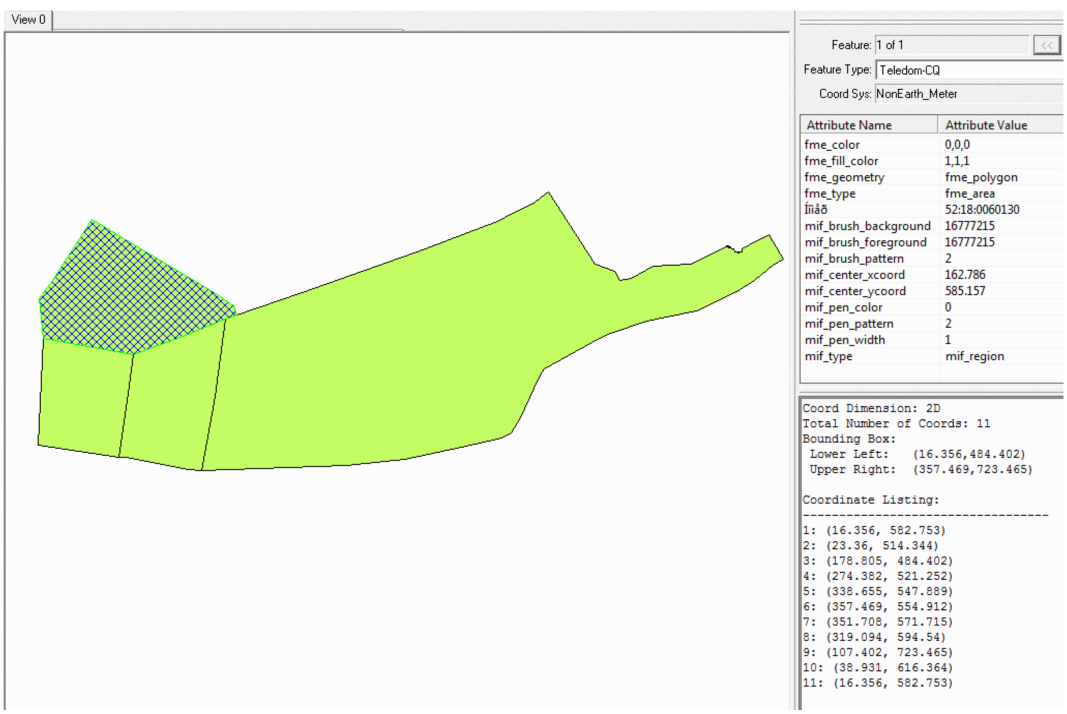

Figure 14. A few cadastre blocks near Teledom building(SDO_BLOCK table).

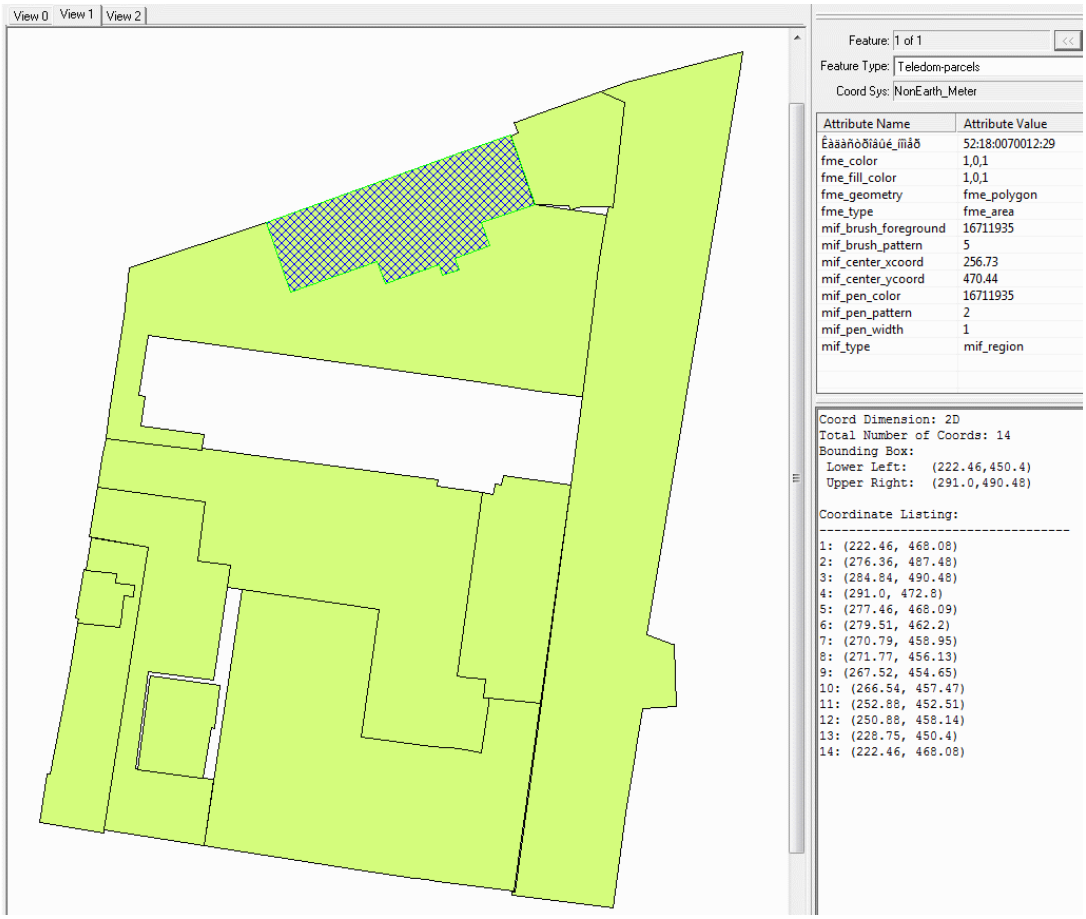

Figure 15. A few cadastral land parcels near Teledom building (SDO_PARCEL table).

6. Technical model

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 recording. These 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 analyzing the Cadastre in the Russian Federation, the following guidelines are defined for the registration of new 3D parcels (cadastral objects):

- Two representations are required for a 3D parcel: 1. PDF (contains the visualization) and 2. LADM / CityGML (contains the 3D data to be further used in the land registration process);
- For normal parcels 3D polyhedron is a sufficient description;
- For 3D linear parcels (including pipeline) an additional option would be the following: an attached (multi-) polyline diameter or height and width;
- New 3D parcel that crosses multiple land parcels (for example a pipeline) requires the transfer of the ownership (or other rights) of the involved 3D spaces from the existing parcels to the single new 3D parcel), see explanation below, just before the start of subsection 6.1;
- A 3D parcel has a (temporary) ID.
- For reference, the following topographic objects are required: 3D buildings (rooms), roads, pipelines and cables and relevant surface with height;
- Accuracy 3D object is equal to 2D object (15 cm). A face must be within 15 cm of a flat plane. Note that the accuracy value depend on the category of land (and 15 cm is the value for urban areas).
- Horizontal and vertical reference: standard Oblast Nizhny use
- Height (z) coordinate: absolute (vertical reference) required and relatively (compared to Earth's surface) is optional;
- Curved surfaces represented by multiple flat edges (this model will remain relatively well implementable);

The preference is to store the 3D parcels in the same database table as the 2D parcels; see section 6.3. 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 (no database schema change). An alternative would be to store these in additional SDO_GEOMETRY attributes. The new 3D parcels have to be validated against the existing area's (2D parcels) and 3D objects: are the rights properly transferred. The above guidelines are intended for the initial registration. 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">
```

Again, 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). This is caused by the fact that a normal land parcel (described in 2D) actually corresponds to a column in 3D space representing a volume of ownership. When a new 3D parcel is created and it crosses multiple land parcels, then this could be compared to a split of the existing land parcels (a part of the ownership is taken out of the 3D volume/column) and together the split parts form the new 3D parcel.

6.1 Documents in 3D PDF

Below an example of a 3D PDF document taken from the Dutch 3D NL pilot showing possible 3D Cadastral parcel; see Figure 16. 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 3D drawing: rotating, scaling, slicing, selecting, etc. However, it is not possible to directly extract the 3D geometry, for subsequent storage in the database. For this purpose, also the XML document with data has to be submitted (see next section).

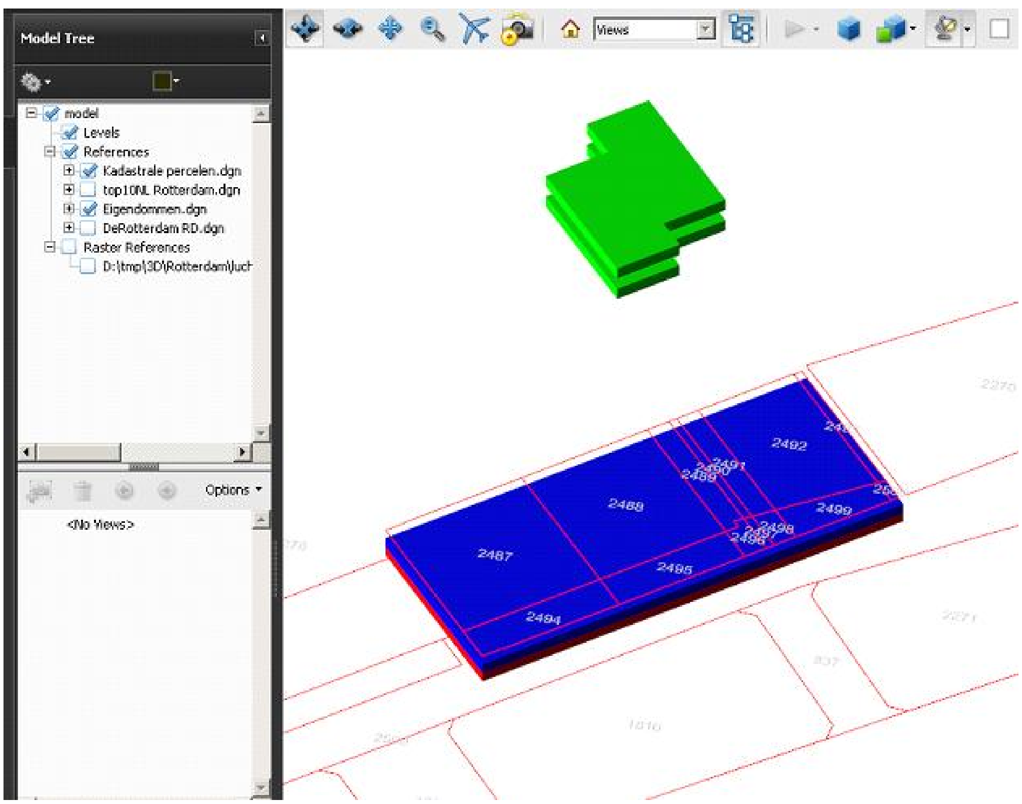

Figure 16. 3D PDF example, from Dutch 3D NL pilot (by Kees van Prooijen, Bentley Systems).

6.2 Data in XML

The actual encoding of the 3D Parcel (as part of the initial recording/survey plan) will be done in the XML standard format. Figure 17 shows a possible integration of LADM-3D and CityGML (OGC standard for 3D spatial objects based on XML encoding; see Chapter 3), where explicit links between 3D cadastral objects (as in LA_LegalSpaceBuildingUnit LADM) and its physical counterpart (part of building CityGML) can be modelled. In the initial phase of the project, it is proposed not to include the explicit associations.

Annex A shows an example of the actual XML encoding of 3D Parcel using standard CityGML (XML) format. A 3D parcel is encoded with a generic CityGML class and this is tagged with the corresponding LADM class name; e.g. for legal space building unit: <generic:class>LA_LegalSpaceBuildingUnit</generic:class>. For the Russian Federation the appropriate Russian tags should be used here, that is, RF_LandParcel, RF_LegalSpaceBuilding, RF_LegalSpaceBuildingUnit, RF_LegalSpaceOtherConstruction, and RF_LegalSpaceUnfinished.

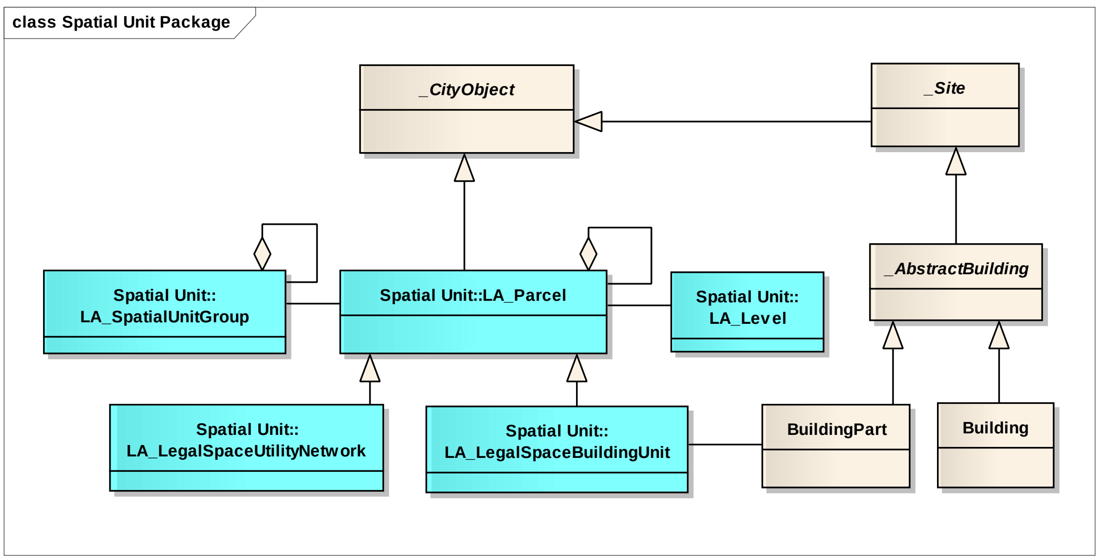

Figure 17. Possible integration of LADM-3D and CityGML.

6.3 3D data in the database

The existing database schema of the Russian cadastre (see Chapter 5) does not (or hardly) need to be adopted. In the legal/ administrative side there are no changes at all (as was concluded in the wrap-up meeting from 20-23 June 2011 visit). 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. However, if an older version of Oracle is used then the geometry subtype ‘multipolygon’ should be used. In this case there is more responsibility at the side of the application to make sure the proper polygons, that is faces of the polyhedron, are provided to form a closed volume. Perhaps one additional attribute could be added: ‘diameter’ (if equal to -2 then this is a normal polygon, if equal to -3 the this is a normal polyhedron, if larger or equal to 0 then this specifies the diameter of a ‘multicurve’).

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.

7. Conclusion

In this report the background, three typical 3D cases for registration, various options for 3D models and formats (in general), and finally the designed conceptual and technical models for 3D cadastre in the Russian Federation have been described and documented. The technical model is reflected in the PDF document and XML data of the survey plan for the initial registration. The database schema does not need to be adopted because of the selected technical solution (polyhedron-based or multipolyline with diameter-based), which fits in Oracle spatial SDO_GEOMETRY type (as well as 2D polygons do).

In the next phase of the project, the prototype will develop functionality to illustrate and test the possible future workflow around 3D parcels in Russia: accepting newly registered 3D parcels, and correctly storing them into the database for possible future access. The prototype will include a component for registration and a web-based component for dissemination. The initial test data, including selected 3D cases, will be from Nizhegorodskaya Oblast, which has been selected as pilot region in this project. The territorial division of Rosreestr of Nizhegorodskaya Oblast is actively involved in the project, as well as the Nizhny Novgorod City Administration (with 1,9 million inhabitants). The specialists of Rosreestr and Land Cadastre Chamber in Nizhegorodskaya Oblast provide the local data needed for the pilot to the Dutch developers of the prototype.

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Annex A. Example XML encodings of 3D Parcel

To clarify the XML format for the registration of a new 3D parcel, below two examples of 3D Parcels:. 1. LADM class 'LA_LegalSpaceBuildingUnit' in CityGML using gml:Solid (Annex A.1) and 2. LADM class 'LA_LegalSpaceUtilityNetwork' in CityGML using gml:MultiVurve (Annex A.2). In Annex A.1 the solid is defined by seven faces and illustrated in Figure 18. Note that (see the red text in the XML below) the CityGML generic class is used and the 3D parcel is a LOD4 geometry (high accuracy and potentially indoors).

A.1 Polyhedral (solid) example 3D parcel

```
<?xml version="1.0" encoding="utf-8"?>
<CityModel xmlns="http://www.opengis.net/citygml/1.0"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xlink="http://www.w3.org/1999/xlink"
  xmlns:generic="http://www.opengis.net/citygml/generics/1.0"
  xmlns:gml="http://www.opengis.net/gml"
  xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0
http://schemas.opengis.net/citygml/1.0/cityGMLBase.xsd
http://www.opengis.net/citygml/generics/1.0
http://schemas.opengis.net/citygml/generics/1.0/generics.xsd">
  <gml:name>TU Delft example 3D Parcel for Cadastre</gml:name>
  <gml:boundedBy>
      <gml:Envelope srsDimension="3" srsName="urn:ogc:def:crs:EPSG:7.6:7415">
      <gml:lowerCorner srsDimension="3">84936.169 444962.883 0.0 </gml:lowerCorner>
      <gml:upperCorner srsDimension="3">86082.217 446807.742 90.0 </gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
  <cityObjectMember>
    <generic:GenericCityObject gml:id="Parcel_1">
      <creationDate>2011-04-01</creationDate>
      <generic:class>LA_LegalSpaceBuildingUnit</generic:class>
      <generic:lod4Geometry>
        <gml:Solid>
          <gml:exterior>
            <gml:CompositeSurface>
              <gml:surfaceMember>
                <gml:Polygon>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:pos>85514.91 445173.489 0.0</gml:pos>
                      <gml:pos>85511.709 445170.399 0.0</gml:pos>
                      <gml:pos>85510.892 445172.368 0.0</gml:pos>
                      <gml:pos>85514.066 445175.521 0.0</gml:pos>
                      <gml:pos>85514.91 445173.489 0.0</gml:pos>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon>
                  <gml:exterior>
                    <gml:LinearRing>
                      <gml:pos>85514.066 445175.521 10.7</gml:pos>
                      <gml:pos>85510.892 445172.368 10.7</gml:pos>
                      <gml:pos>85511.709 445170.399 10.7</gml:pos>
                      <gml:pos>85514.91 445173.489 10.7</gml:pos>
                      <gml:pos>85514.066 445175.521 10.7</gml:pos>
                    </gml:LinearRing>
                  </gml:exterior>
                </gml:Polygon>
              </gml:surfaceMember>
              <gml:surfaceMember>
                <gml:Polygon>
                  <gml:exterior>
```

```
                <gml:LinearRing>
                  <gml:pos>85510.892 445172.368 0.0</gml:pos>
                  <gml:pos>85510.892 445172.368 5.4</gml:pos>
                  <gml:pos>85510.892 445172.368 10.7</gml:pos>
                  <gml:pos>85514.066 445175.521 10.7</gml:pos>
                  <gml:pos>85514.066 445175.521 0.0</gml:pos>
                  <gml:pos>85510.892 445172.368 0.0</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Polygon>
              <gml:exterior>
                <gml:LinearRing>
                  <gml:pos>85514.91 445173.489 0.0</gml:pos>
                  <gml:pos>85514.91 445173.489 10.7</gml:pos>
                  <gml:pos>85511.709 445170.399 10.7</gml:pos>
                  <gml:pos>85511.709 445170.399 5.4</gml:pos>
                  <gml:pos>85511.709 445170.399 0.0</gml:pos>
                  <gml:pos>85514.91 445173.489 0.0</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Polygon>
              <gml:exterior>
                <gml:LinearRing>
                  <gml:pos>85514.066 445175.521 0.0</gml:pos>
                  <gml:pos>85514.066 445175.521 10.7</gml:pos>
                  <gml:pos>85514.91 445173.489 10.7</gml:pos>
                  <gml:pos>85514.91 445173.489 0.0</gml:pos>
                  <gml:pos>85514.066 445175.521 0.0</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Polygon>
              <gml:exterior>
                <gml:LinearRing>
                  <gml:pos>85511.709 445170.399 0.0</gml:pos>
                  <gml:pos>85511.709 445170.399 5.4</gml:pos>
                  <gml:pos>85510.892 445172.368 5.4</gml:pos>
                  <gml:pos>85510.892 445172.368 0.0</gml:pos>
                  <gml:pos>85511.709 445170.399 0.0</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
          <gml:surfaceMember>
            <gml:Polygon>
              <gml:exterior>
                <gml:LinearRing>
                  <gml:pos>85511.709 445170.399 5.4</gml:pos>
                  <gml:pos>85511.709 445170.399 10.7</gml:pos>
                  <gml:pos>85510.892 445172.368 10.7</gml:pos>
                  <gml:pos>85510.892 445172.368 5.4</gml:pos>
                  <gml:pos>85511.709 445170.399 5.4</gml:pos>
                </gml:LinearRing>
              </gml:exterior>
            </gml:Polygon>
          </gml:surfaceMember>
        </gml:CompositeSurface>
      </gml:exterior>
    </gml:Solid>
  </generic:lod4Geometry>
 </generic:GenericCityObject>
</cityObjectMember>
</CityModel>
```

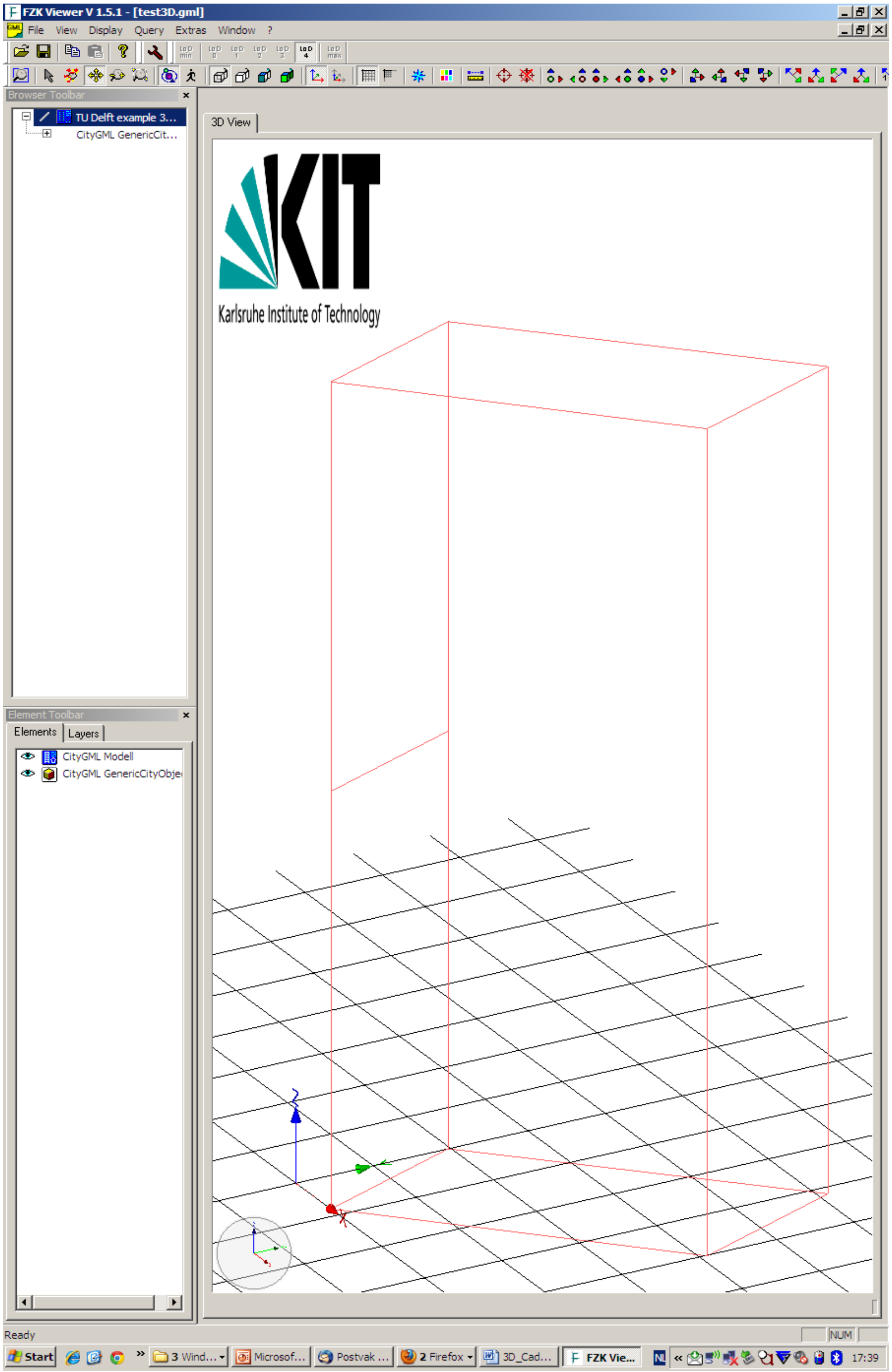

Figure 18. The seven faces of the 3D-LADM/CityGML solid visualised (In FZK viewer)

A.2 MultiCurve example 3D parcel


```
<?xml version="1.0" encoding="utf-8"?>
<CityModel xmlns="http://www.opengis.net/citygml/1.0"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xlink="http://www.w3.org/1999/xlink"
  xmlns:generic="http://www.opengis.net/citygml/generics/1.0"
  xmlns:gml="http://www.opengis.net/gml"
  xsi:schemaLocation="http://www.citygml.org/citygml/1/0/0
http://schemas.opengis.net/citygml/1.0/cityGMLBase.xsd
http://www.opengis.net/citygml/generics/1.0
http://schemas.opengis.net/citygml/generics/1.0/generics.xsd">
  <gml:name>TU Delft example 3D Parcel for Cadastre, utility network/ multicure</gml:name>
  <gml:boundedBy>
      <gml:Envelope srsDimension="3" srsName="urn:ogc:def:crs:EPSG:7.6:7415">
      <gml:lowerCorner srsDimension="3">84936.169 444962.883 0.0 </gml:lowerCorner>
      <gml:upperCorner srsDimension="3">86082.217 446807.742 90.0 </gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
  <cityObjectMember>
    <generic:GenericCityObject gml:id="Parcel_2">
      <creationDate>2011-06-21</creationDate>
      <generic:class>LA_LegalSpaceUtilityNetwork</generic:class>
      <generic:lod4Geometry>
        <gml:MultiCurve>
          <gml:curveMember>
            <gml:LineString>
              <gml:pos>85524.91 445173.489 0.0</gml:pos>
              <gml:pos>85521.709 445170.399 0.0</gml:pos>
              <gml:pos>85520.892 445172.368 0.0</gml:pos>
              <gml:pos>85524.066 445175.521 0.0</gml:pos>
            </gml:LineString>
          </gml:curveMember>
          <gml:curveMember>
            <gml:LineString>
               <gml:pos>85520.892 445172.368 0.0</gml:pos>
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