

Design of the 3D Cadastre Model and Development of the Prototype in the Russian Federation

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Key words: 3D Cadastre, Standards, Cadastral Modelling, Prototype

SUMMARY

This paper presents 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. The project is currently in the phase of the completing the design of a 3D Cadastral model. The first steps of the development of a prototype system have recently be taken.

РЕЗЮМЕ

В данной работе представлен текущий проект по созданию модели трехмерного кадастра объектов недвижимости в Российской Федерации. Целью данного проекта является разработка прототипа и создание благоприятных правовых и институциональных условий для внедрения 3D кадастра в России на основе опыта Нидерландов и других стран. В настоящее время проект находится на стадии завершения разработки 3D модели кадастра. Начата разработка прототипа системы.

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1. INTRODUCTION

This paper presents the on-going project on 3D cadastre modelling in the Russian Federation. The context and scope of this project have been published earlier, including a selection of typical 3D cases to be registered (Vandysheva et al, 2011). The project aims to prepare the introduction of 3D cadastre registration in the Russian Federation. After the initial analysis of the Russian legislation, an 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 project is based on experience of the Netherlands (Stoter, 2004; Stoter and Van Oosterom, 2005) and other countries (van Oosterom et al, 2011).

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 registration. However, the Russian Federation has a strong drive towards a 3D cadastre for better registration of complex buildings, or other types of constructions, and subsurface networks (e.g., cables and pipelines).

Rosreestr is responsible for all tasks related to the registration of rights, recording of parcels (cadastral map) and geodetic and (topographic) mapping. Rosreestr has about 6,500 offices and 60,000 staff members. Since the start of the Russian Federation approximately 80 million parcels have been registered together with associated rights and restrictions (responsibilities) and the involved parties. Therefore Rosreestr maintains probably the world's largest cadastral system. Both information on parcels and the legal and administrative information can be accessed online by the public (<http://maps.rosreestr.ru/Portal/>). Rosreestr falls under the authority of the Ministry of Economic Development of the Russian Federation being the project counterpart.

This paper starts with an overview of the current cadastral (legal and spatial) model in the Russian Federation and relates this to the terminology of the Land Administration Domain Model (LADM; ISO DIS 19152, 2011). Section 3 discusses the extension of the model into 3D, covering both the conceptual and technical aspects. The various types of data used for the developments of the prototype system are presented in Section 4. The requirements for the prototype development are then given in Section 5 together with a first sketch of the prototype system architecture. The paper ends with concluding remarks in Section 6.

2. CURRENT CADSATRAL MODEL

The current cadastral parcel registration system is 2D polygon-based, in the terminology of the LADM (ISO DIS 19152, 2011). 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 (Schema_Cadastr) and ‘Registration’ database (Schema_Right). Table 1 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 2 lists the tables which are important for the geographic representation and Figure 1 shows a part of the technical model (tables) of Cadastre database covering cadastre blocks and land parcels. The geometry attribute in the SDO_ tables is called GEOLoc and uses the Oracle spatial data type SDO_GEOMETRY.

Table 1. Relationship between LADM concepts and the Cadastre and Registration databases of Rosreestr

LADM entity	Tables in the databases	
	Schema Cadastre	Schema Registration
LA_BAUnit	Obj,Reg	Oni_List
LA_Party	Right_Owner*,Encumbrance_Owner*	JRDP_List,PRS NF_List
LA_RRR	Right,Encumbrance	EGRP_*
LA_SpatialUnit	Entity_Spatial	-
LA_AdministrativeSource	Doc	EGRP_DocBS
LA_Source	EDoc_Info	-

Table 2. Tables in the Cadastre database, which are relevant for geographic information

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

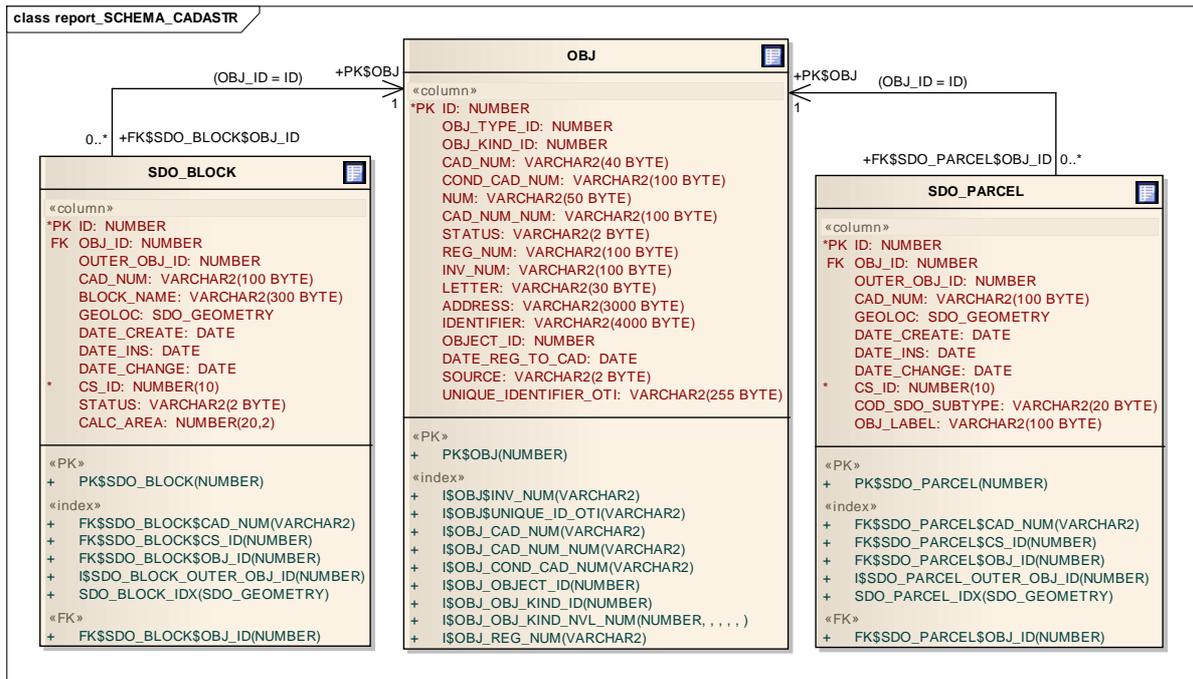


Figure 1. Part of the Cadastre database (technical) model covering cadastre blocks and land parcels

3. 3D CADASTRE MODEL

In the first subsection the 3D extension is discussed with respect to the conceptual model. In subsection 3.2 the technical, implementation oriented, model is discussed. Then the actual data representations within this model are discussed in the next subsections for the various formats: 3D PDF, XML and Oracle database.

3.1 Conceptual model 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. 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 multicurve with diameter (curved surfaces around pipelines). A topologically structured 3D Cadastre, is not conform the current 2D Russian Land Registry, which has no topology. The motivations in favour of the selected approach, besides that it does support the needs of the analyzed 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 multicurve 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 multicurves 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).

3.2 Technical model for database and submission

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. 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 guidelines are defined for the registration of new 3D parcels/cadastral objects (Vandysheva et al, 2011).

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 3D objects: are the rights properly transferred. The mentioned 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).

3.3 Documents in 3D PDF

Below an example of a 3D PDF document taken from the Dutch 3D NL (Stoter et al, 2011) pilot showing possible 3D Cadastral parcel; see Figure 2. 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).

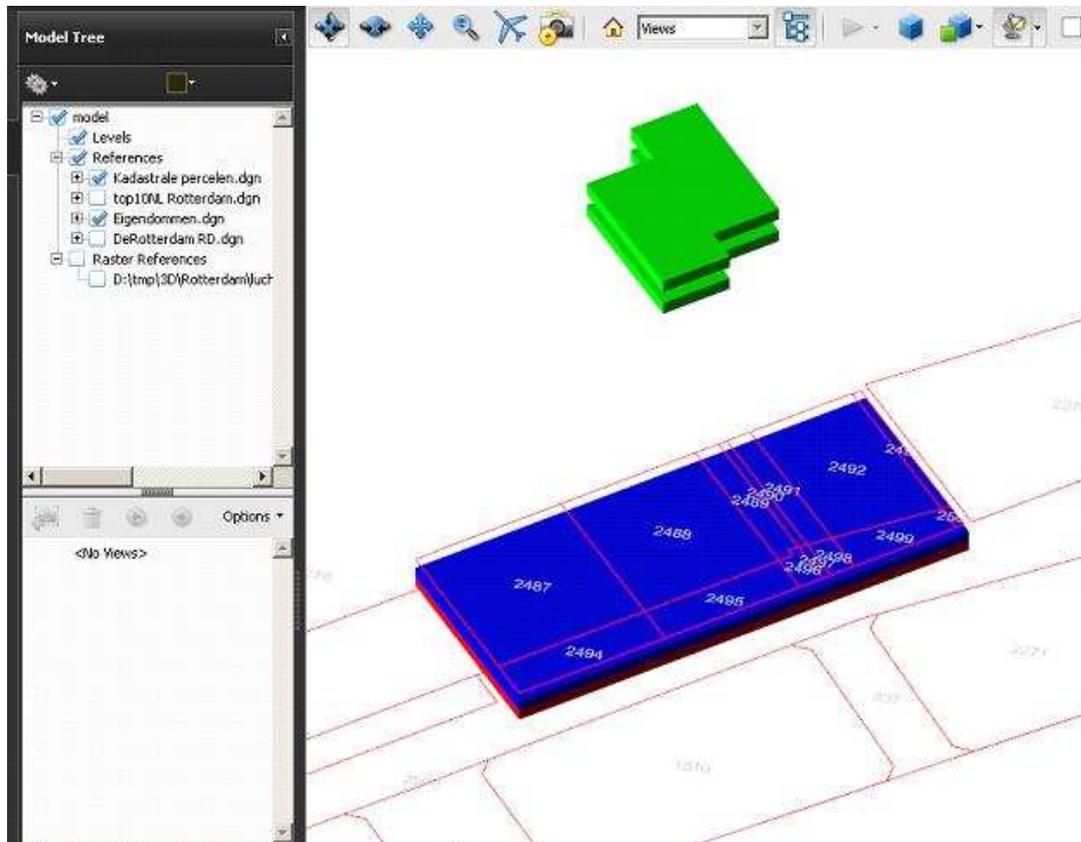


Figure 2. 3D PDF example, from Dutch 3D NL pilot (by Kees van Prooijen, Bentley Systems)

3.4 3D data in XML

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.

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 (to extend the CityGML model) 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.

3.5 3D data in the Oracle database

The existing database schema of the Russian cadastre (see Section 2) 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 equal to -2 then this is a normal 2D polygon, if equal to -3 the this is a normal 3D 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.

4. 3D SAMPLE DATA FOR THE PROTOTYPE

In this section the test data is presented for three selected cases. 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); see Figure 3.
2. Case 2 is the apartment complex, 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; see Figure 4.
3. Case 3 is a short underground gas pipeline of low pressure, located at the address: Nizhniy Novgorod, Nizhegorodskiy district, from Piskunov str. to Verhnevolzhskaya naberezhnaya, 7 (see Figure 5). 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.

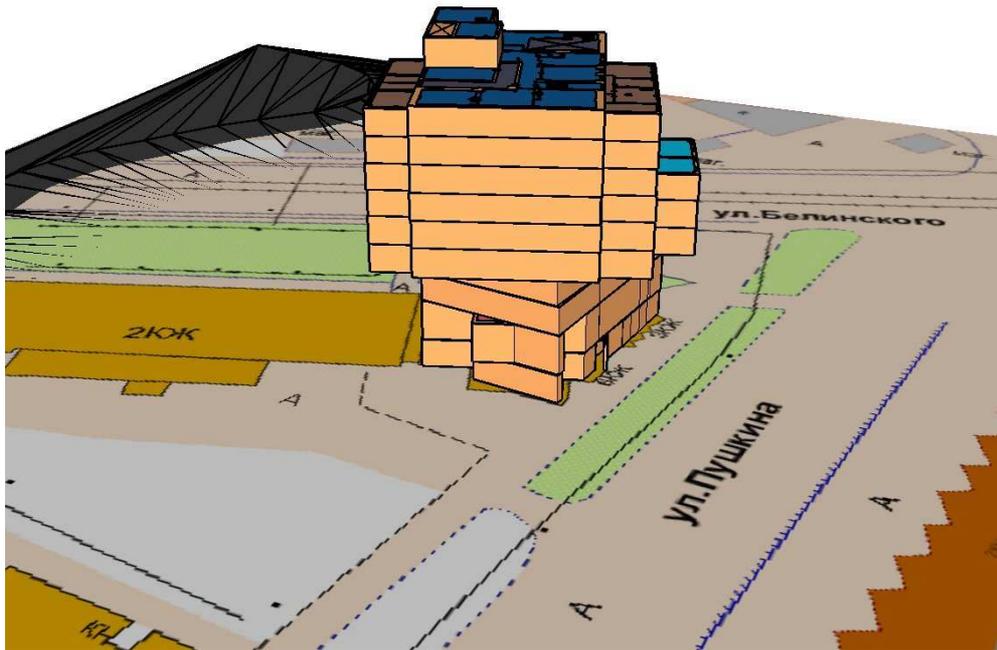


Figure 3. Teledom building placed on DTM draped with topographic map for orientation

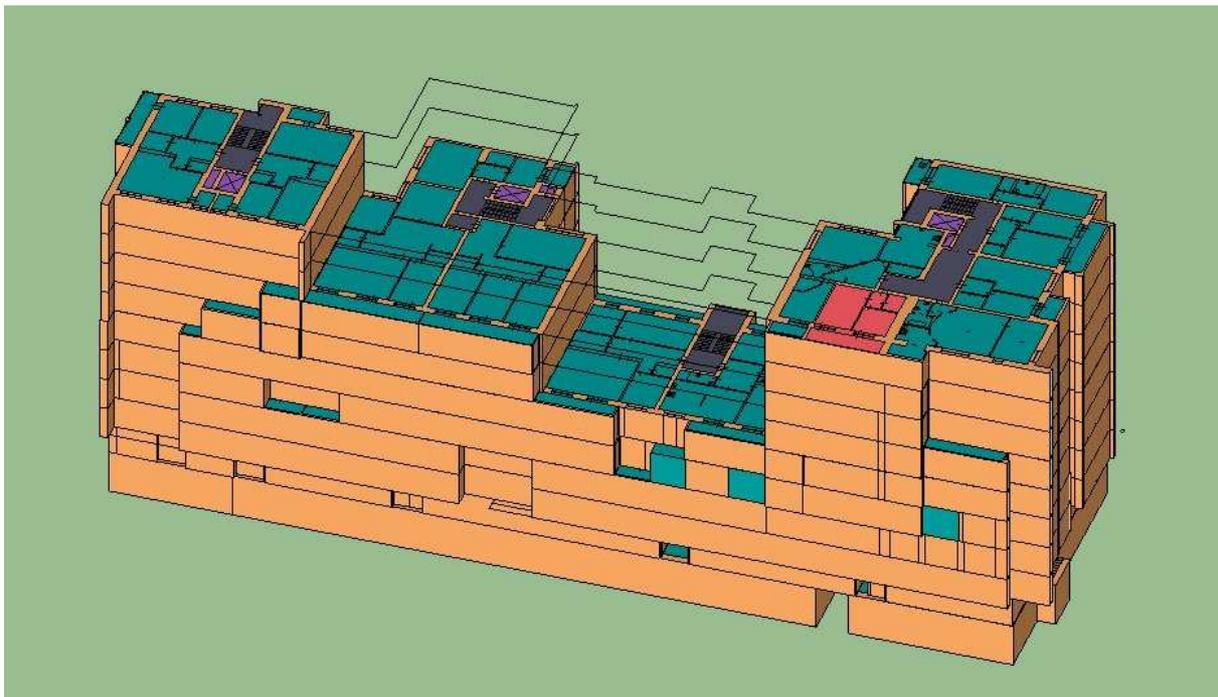


Figure 4. The apartment complex 66a Ulitsa Nevzorovykh



Figure 5. Top: Cadastral map fragment including the pipeline, bottom: two different 3D views

5. PROTOTYPE DEVELOPMENT

For the development of the prototype first the essential functionality will be built, which will result in a ‘proof-of-concept’. The functional focus of the pilot is on visualization and user interaction within a 3D viewer and less on validation and calculation. The requirements are organized into functional (Table 3) and technical requirements (Table 2). The priorities of these requirements are categorized using the MoSCoW method: M (MUST have); S (SHOULD have this if at all possible; C (COULD have this if it does not affect anything else); and W (WON’T have this time but WOULD like in the future).

The prototype will be developed based on the existing 2D portal with link to a new 3D viewer; see Figure 5. The main technical components of the prototype are the database, the webserver and the 3D web browser. For each component and for the interaction between the components, there are many different technical solutions or platforms possible. For the database Oracle 11g is used as it supports the polyhedron data (sub)type, including validation.

Table 3 Priorities of Functional (F) and Technical (T) Requirements

Category	Requirement	Priority
F-Visualisation	Visualisation of layer with 3D cadastral objects	M
F-Visualisation	Visualisation of layer with the 3D terrain	M
F-Visualisation	Visualisation of layer with 3D reference objects	M
F-Visualisation	Visualisation of underground objects	M
F-Visualisation	Separate layers for different types of 3D cadastral objects	M
F-Visualisation	Rendering the terrain with raster map/image	S
F-Visualisation	Visualisation of Layers with results of calculations	C
F-Visualisation	Separate layers for different types of 3D reference objects	C
F-Visualisation	Adjustable transparency for each layer	C
F-Interaction	Intuitive 3D navigation (zoom/pan/rotate in 3D)	M
F-Interaction	Select and highlight 3D cadastral object	M
F-Interaction	Display attributes of selected 3D cadastral object in browser	M
F-Interaction	Search 3D cadastral object by ID in browser	M
F-Interaction	Select and highlight found 3D cadastral object in browser	M
F-Interaction	Unselect	S
F-Interaction	Zoom and pan to selected 3D object	S
F-Interaction	Switch on/off layers separately	S
F-Interaction	Choose between visualization options for the terrain	C
F-Validation	Calculate volume of 3D cadastral object	S
F-Validation	Validate geometry	S
F-Validation	Check for 3D overlap between 3D cadastral objects	S
F-Validation	Calculate 3D overlap between 3D cadastral objects	C
F-Validation	Calculate intersection of 3D cadastral objects with terrain	C
F-Validation	Calculate projection of 3D cadastral object on terrain	C
F-Miscellaneous	Interface in Russian language	S
F-Miscellaneous	Support of different geo reference systems	C
F-Miscellaneous	Import/export CityGML	W
T-General	Limited programming workload (use existing tools/code)	M
T-General	Free software development toolkit available for 3D browser	M
T-General	Technical components must fit in existing technical environment	M
T-General	No installation needed on client (plugin/applet is ok)	M
T-General	3D web browser supports Microsoft Internet Explorer 7 & higher	M
T-General	3D web browser supports Apple Safari	S
T-General	3D web browser supports Mozilla Firefox	S
T-General	3D web browser supports Google Chrome	S
T-General	3D web browser launchable via click in existing 2D map browser	S
T-General	Technical components are supported by active communities	S
T-Database	3D cadastral objects modelled as polyhedrons	M
T-Database	3D objects stored as SDO_geometry in Oracle 11	S
T-Database	3D linear cadastral objects also modelled as 3D multicurves	C

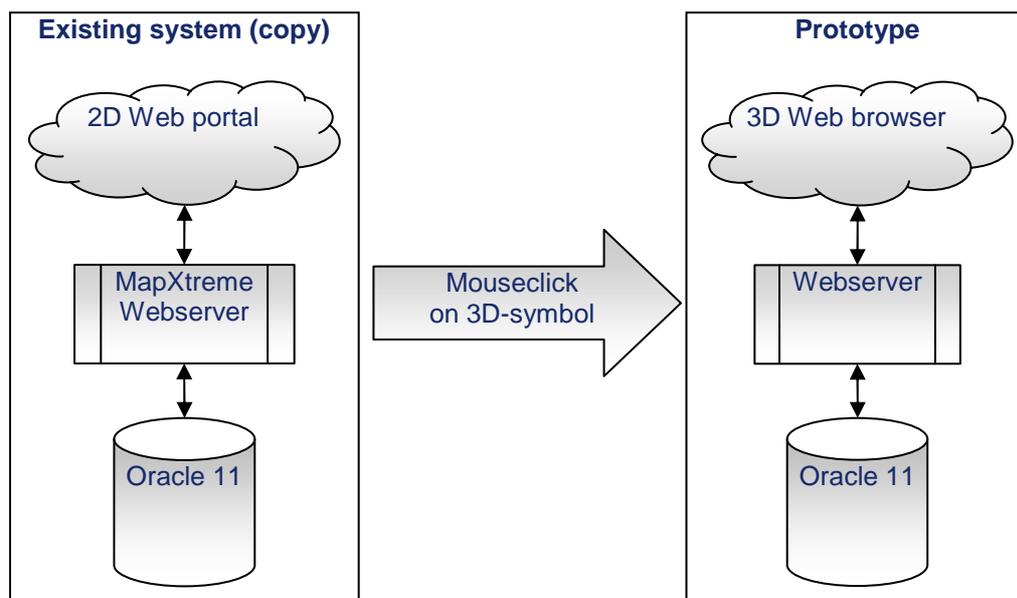


Figure 6. The 3D viewer as extension of the current 2D portal (note the two depicted Oracle databases could be implemented as a single database)

For the webserver and 3D web browser and the interactions, various solutions have been investigated and assessed based on the priorities of the requirements; see Table 3. It was decided to use the open source viewer XNavigator. This viewer is developed at the University of Bonn and the source code is available (<http://sourceforge.net/projects/xnavigator/>). XNavigator uses OGC's Web 3D Service (W3DS: <http://www.w3ds.org/>) for visualizing in 3D. W3DS is designed for efficient 3D data transport and uses X3D (or VRML) as data format. X3D is a standard for 3D on the web (<http://www.web3d.org/about/overview/>) and is the successor of VRML.

The server application will be implemented in Java (EJB) and will run on a Java Application Server (GlassFish, Tomcat ...). The server application will have 3 main layers: 1. collecting data from the database, 2. business logic, and 3. W3DS service. Eclipselink (<http://www.eclipse.org/eclipselink/>) will be used to collect data from the database and automatically transform these data to objects. Eclipselink can automatically transform `sdo_geometry` into JGeometry objects; see Figure 7. In proof-of-concept (fast implementation) the 3D geometry will be prepared as X3D files. So the server application (business logic part) does not have to transform the geometry (via JGeometry) to X3D.

A pilot environment is created for the existing 2D cadastral portal, so it can be modified. Only the data of the pilot area has to be included in the pilot environment. At each location where 3D information is available in the prototype, a symbol is added to the 2D cadastral map of the pilot environment. The symbols have an attribute, containing an URL to launch the 3D web browser. To show the corresponding 3D-objects at this location in the 3D web browser, the URL must contain an identifier or an X,Y location. The first time that the 3D web browser is used, the installation of a Java applet in the web browser will have to be accepted.

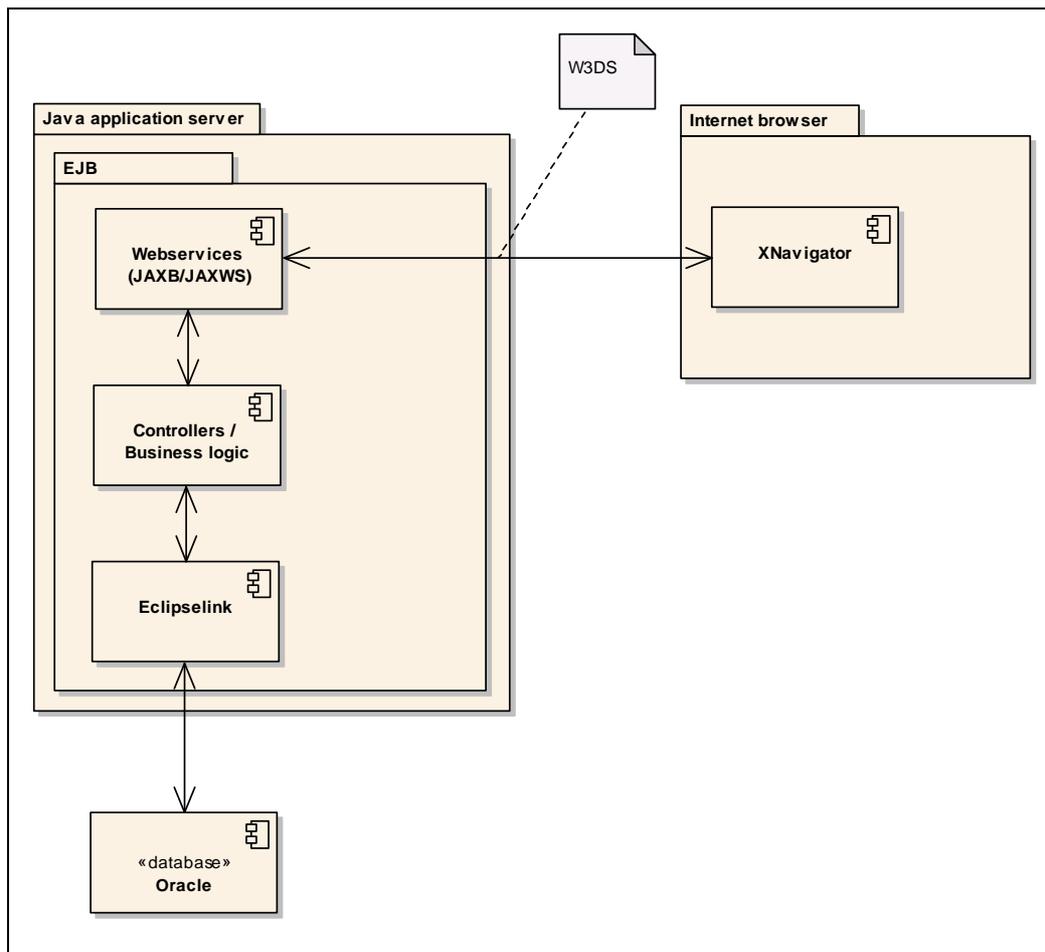


Figure 7. Technical architecture of the 3D Cadastre prototype

6. CONCLUSION

In this paper 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 adapted because of the selected technical solution (polyhedron-based or multicurve with diameter-based), which fits in Oracle spatial SDO_GEOMETRY type (as well as 2D polygons do).

Further, the prototype functionality has been described. Based on the priorities of both various functional and technical requirements a design for the prototype has been described. After completion this prototype can be used 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 initial test data, including selected 3D cases, is from Nizhegorodskaya Oblast, which has been selected as pilot region in this project. The experiences from the pilot will be used to prepare the guidelines for the future 3D registration: both the legal aspects and the technical workflow.

ACKNOWLEDGEMENTS

The authors of this paper would like to express their gratitude to the (current and past) partners and colleagues within the project: Oleg Schwarz, Modest Yakubovich, Vladimir Tikhonov, Vasily Romanov, Irina Yufereva, Natalia Korionova, Veliko Penkov, Andres Hoogeveen, Rik Wouters, Chrit Lemmen and Hendrik Ploeger.

This research is supported in part by the Dutch Technology Foundation STW (project numbers 11300 and 11185), which is part of the Netherlands Organisation for Scientific Research (NWO) and partly funded by the Ministry of Economic Affairs, Agriculture and Innovation.

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BIOGRAPHICAL NOTES

Natalia Vandysheva holds a PhD in Physics and Mathematics from S.-Petersburg University, Russia. About 30 years experience in spatial data processing, digital mapping, GIS applications for land monitoring and cadastre. Since 2000 works as the head of the Spatial Data department in the Federal Cadastral Centre “Zemlya”(“Land”) being responsible for digital cartography and creation of cadastre information systems on the basis of GIS-technologies. Now is also involved in creation of SDI of the Russian Federation that are implemented under the direction of the Rosreestr (Federal Service for State Registration, Cadastre and Mapping). Project leader or expert in many international projects (USA, UNEP, EU countries).

Anatoly Ivanov graduated in 2007 from the faculty "Geodetic", engineer on a speciality an applied geodesy of "Moscow State University of Geodesy and Cartography". Since 2011 works as the Deputy Director in the Federal Cadastral Centre “Zemlya”(“Land”). Now developing and coordinating the following directions: geodesic and cartographic activities, spatial data infrastructure of the Russian Federation, creation of 3D cadastre in Russia, including legislative regulation, and international cooperation in these areas.

Sergey Pakhomov graduated in 2003 from the faculty "Computer-Aided Design" department "Robotics and integrated automation" of Moscow State University named after Bauman. Since 2005 he has been working in the Federal Cadastral Centre “Zemlya”(“Land”) as one of the main developers and designers of automated system of cadastral AIS GKN as well as other software products required for automation of Rosreestr. Now holds the position of deputy director of the center design and development of automated systems.

Boudewijn Spiering obtained an MSc in Geodetic Engineering in 1991 from Delft University of Technology, The Netherlands. He is currently advisor GIS & ICT at Grontmij Nederland BV. Grontmij is a leading sustainable design, engineering and management consultancy active in the growth markets of water, energy, transportation and sustainable planning and design. His specializations include GIS, ICT, (Geo-) Information Management, Information Architecture, Data Management, Data Analysis, E-government, and various geo-applications for the (local) Dutch Government.

Jantien Stoter defended her PhD thesis on 3D Cadastre in 2004, for which she received the prof. J.M. Tienstra research-award. From 2004 till 2009 she worked at the International Institute for Geo-Information Science and Earth Observation, ITC, Enschede, the Netherlands (www.itc.nl). As associate professor at ITC she led the research group in the field of automatic generalization. She was project leader of an EuroSDR project on generalisation from 2005 till 2009. Since October 2009, she fulfils a dual position: one as Associate Professor at Section GIS technology at OTB and one as Consultant Product and Process Innovation at the Kadaster. From both employers she is posted to Geonovum. The topics that she works on are 3D, information modeling and multi-scale data integration. Since January 2010 she leads the 3D pilot that aims at establishing a 3D reference model in The Netherlands in a collaboration of 55 partners. In November 2010 she received a VIDI grant, which is a

prestigious award given by the Netherlands Organisation for Scientific Research (NWO) for excellent senior researchers.

Sisi Zlatanova is an associate professor and leading the theme group 'Geo-information for Crisis Response' at the GIS Technology department, OTB, the Delft University of Technology, the Netherlands. She has graduated as a surveyor at the University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria in 1983 and has obtained her PhD degree on '3D GIS for urban modelling' at the Graz University of Technology, Graz, Austria in 2000. She is teaching several courses related to 3D GIS, 3D databases and their application for disaster management within TU Delft, the University of Venice (2007, 2008). Her research interests are in 3D geo-information and their applications for emergency management (especially flood management). She is chair and co-chair of several conferences among which Gi4DM, 3Dgeoinfo and UDMS. During September- December 2011 she is on sabbatical at the University of Cape Town (UCT), South Africa, Faculty of Engineering and Built Environment, School of Architecture, Planning and Geomatics.

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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>

```

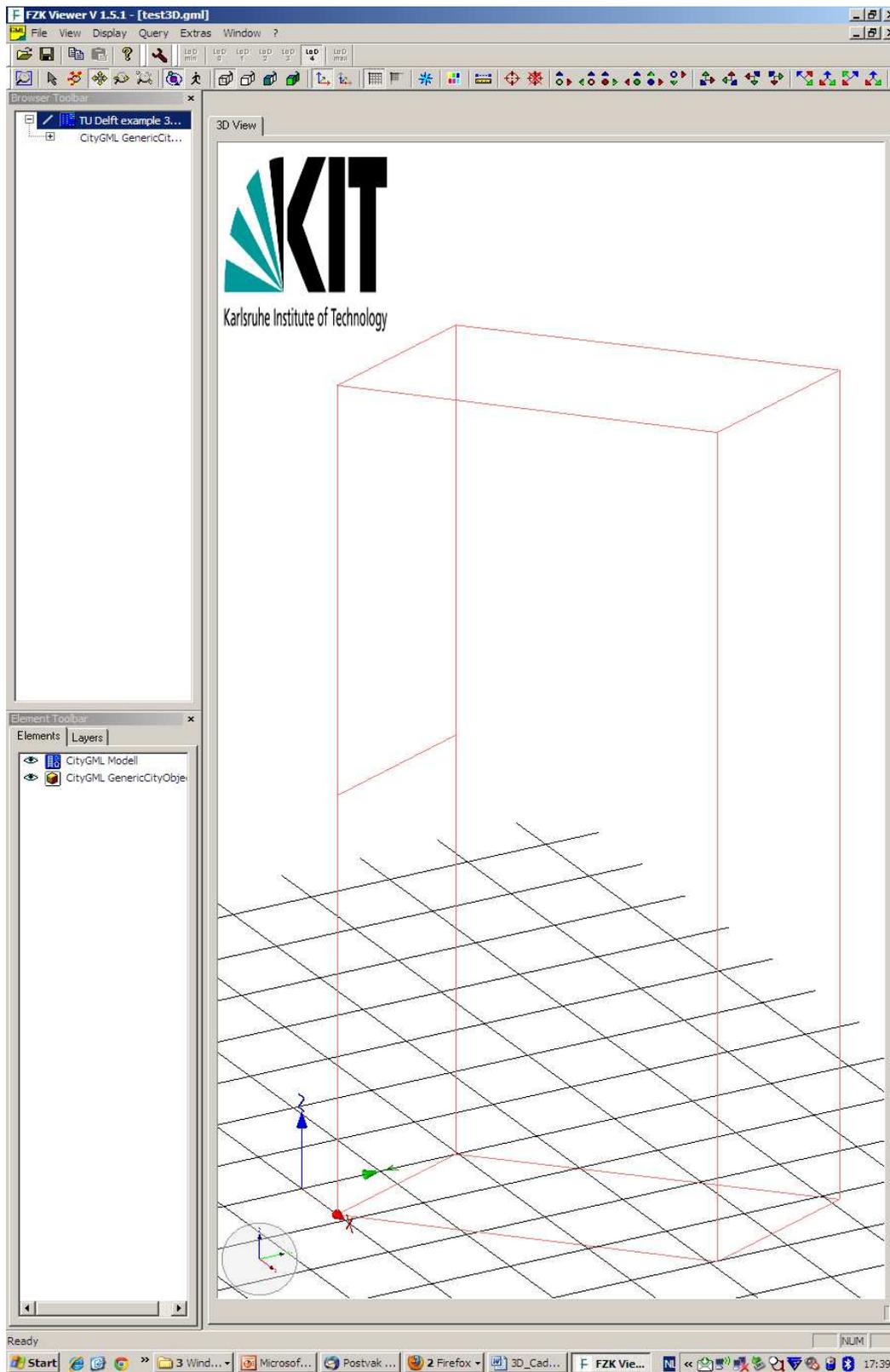


Figure 8. The seven faces of the 3D-LADM/CityGML solid visualised (In FZK viewer)

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>
              <gml:pos>85520.892 445172.368 5.4</gml:pos>
              <gml:pos>85526.892 445177.368 10.7</gml:pos>
              <gml:pos>85525.066 445173.521 10.7</gml:pos>
            </gml:LineString>
          </gml:curveMember>
          <gml:curveMember>
            <gml:LineString>
              <gml:pos>85524.91 445173.489 0.0</gml:pos>
              <gml:pos>85523.91 445176.489 10.7</gml:pos>
              <gml:pos>85522.709 445173.399 10.7</gml:pos>
              <gml:pos>85521.709 445171.399 5.4</gml:pos>
            </gml:LineString>
          </gml:curveMember>
        </gml:MultiCurve>
      </generic:lod4Geometry>
    </generic:GenericCityObject>
  </cityObjectMember>
</CityModel>
```

Natalia Vandysheva, Anatoly Ivanov, Sergey Pakhomov, Boudewijn Spiering, Jantien Stoter, Sisi Zlatanova and Peter van Oosterom
Design of the 3D Cadastre Model and the Development of the Prototype in the Russian Federation

2nd International Workshop on 3D Cadastres
16-18 November 2011, Delft, the Netherlands