Free and Open Source Software for Land Administration Systems: A Hidden Treasure?

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SUMMARY

The open source movement has attracted world-wide attention, and open source software is increasingly used as an alternative to proprietary software products. Yet, there is little evidence of the use of open source software in digital land administration systems.

During the last five years, there have been great advances in the development of open source software products. Database products PostgreSQL and MySQL have matured, and due to the development of spatial extensions, they can also be used as spatial data stores for cadastral datasets. For long time, open source GIS software (OSG) products were unable to match the capabilities of proprietary GIS products, especially when it comes to vector editing functions. However, during the last few years a whole range of new OSG initiatives has started, some of which are becoming real alternatives to proprietary GIS systems. In an attempt to raise awareness on the potential of OSG, this paper looks into the progress of Quantum GIS, uDIG, gvSIG and other OSG initiatives, and assesses the role that they could play in land administration systems.

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1. INTRODUCTION

Just a few years ago, using open source GIS software (OSG) for land administration systems was not really an option. Even though there were several open source GIS products available, these tools were mostly focused on raster GIS and provided little vector editing functions. But since 2002, a whole range of new OSG initiatives have started which open up new possibilities for the use of OSG products in land administration systems. As these open source projects are not marketed as commercial products (their distribution relies on communication between developer communities) they are often unknown to normal GIS users.

In countries that are just now starting to develop their land administration systems, the license and maintenance costs of proprietary software can sometimes form a barrier for the development of sustainable systems. After buying a few software licenses for pilot studies, projects are confronted with budget limitations when it comes to upgrading the software and implementing country-wide land registration programs. With the open source database and GIS tools that are currently available, it is very well possible to build a robust yet low-cost land administration system.

2. SPATIAL DATA REPOSITORIES FOR LAND ADMINISTRATION SYSTEMS

With the development of spatial extensions for most database software products, huge amounts of map data can be efficiently stored and managed in geodatabases. Oracle Spatial is the best known platform for spatial databases, but open source alternatives are growing in popularity. PostGIS is an extension to the PostgreSQL object-relational database system which allows spatial objects to be stored in the database. The strength of PostGIS is that it has become the standard spatial database for all open source GIS tools (Ramsey, 2007). Also MySQL has included spatial functionality in its database core so that it can store geographic features. Both MySQL and PostgreSQL with PostGIS are excellent database products, but PostGIS comes closer to the sophistication of Oracle Spatial when it comes to topology and geometry support.

As demonstrated in Bavaria, Germany, PostgreSQL can be an efficient and reliable data repository for cadastral data. The webportal GeodatenOnline of the Bavarian Office for Surveying and Geographic Information (LVG) is built with open source software and uses PostgreSQL with PostGIS for data storage. With this setup, the Bavarian LVG has been rather successful in its task to provide geoinformation to citizens in a high-tech and cost efficient way (Frankenberger, 2006).

The installation and use of open source database products has become easier over time. In fact, PostgreSQL and MySQL are easier and faster to install than Oracle and occupy less memory and disk space. While in the past the databases had to be managed from the command prompt through SQL commands, Graphic User Interfaces (GUI) such as PgAdmin for PostgreSQL have now been developed so that database administrators can easily add columns, set relationships between tables and manage security settings.

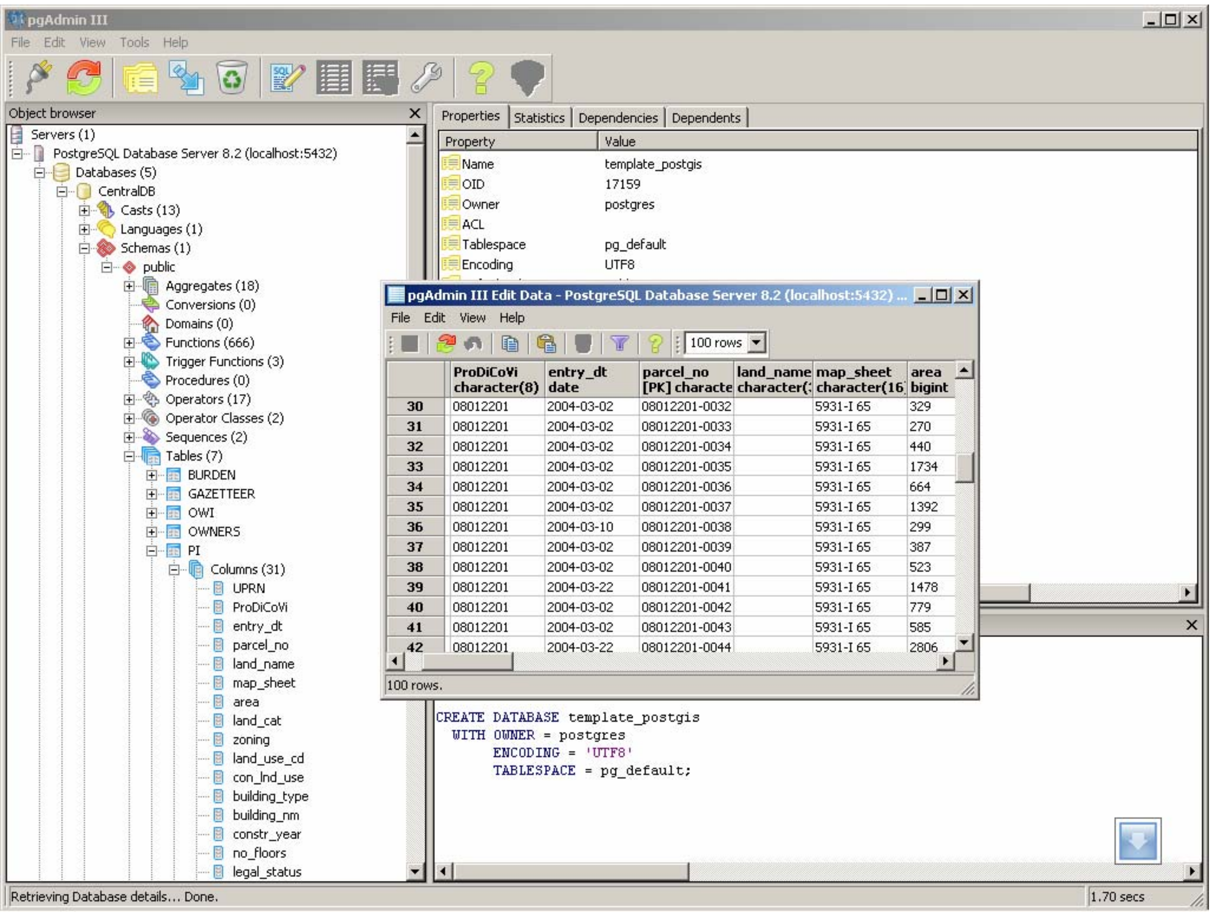

Figure 2-1: The GUI of PostgreSQL allows users to easily create and manage databases

Tasks such as topology checking and spatial analysis that were traditionally handled by GIS desktop software can now be managed efficiently through the spatial database functions that PostGIS provides. With the GEOS geometry engine, PostGIS users can calculate the area of polygon features, convert linestrings to polygons, and perform overlays such as Union, Difference and Intersect. The spatial relationships between geometries can be tested with functions such as Contains(), Distance(), Crosses(), Overlaps(), Touches(), and many others. Using spatial indexing methods to speed up queries, the spatial database functions are consistent with the trend to process and control spatial data centrally on the server side, instead of from the client side.

3. OPEN SOURCE GIS TOOLS FOR LAND ADMINISTRATION SYSTEMS

Even though the spatial database functions can take over many of the data analysis and processing tasks, desktop GIS products are still needed to create, visualize and maintain spatial datasets. Land administration systems vary in their software requirements, but a number of minimum requirements can be identified.

3.1 Typical GIS needs for land administration systems

3.1.1 Editing tools and topology support

To create and maintain accurate cadastral maps, the software must have functions to create polygons, lines and point features, and to edit the geometry of polygon features by adding/deleting/moving vertices. Functions for cutting and merging of polygons are needed for parcel subdivisions and consolidations. Additional editing options such as clipping and buffering are useful when creating buffers along roads or around protected areas. To ensure the accuracy of cadastral boundaries, the mapping software must have functions to create and maintain correct topology. When creating features, the user must be able to set a snapping tolerance and snap to existing features. Adjacent polygons should share common boundaries and during cutting and merging of polygons, correct topology must be maintained.

3.1.2 Map projections

The software must support the geographic and projected coordinate systems required for cadastral maps. Cadastral agencies will likely use only one standard coordinate system for cadastral datasets, but when data from different coordinate systems is combined, transformations or on-the-fly projections are needed. In most open source GIS products, the technology required for projections is drawn from the common class libraries PROJ4 (for software written in C or C++) and GeoTools (for the Java based GIS products). Both PROJ4 and GeoTools support a wide range of map projections.

3.1.3 Raster data

When orthophotos or satellite images are used for on-screen digitizing or verification of parcel boundaries, the software must support the raster format of the images to be used. Most GIS software products support common raster formats (TIFF, JPG), some support satellite image formats such as SPOT and Landsat and have image processing functions such as rectification, filtering and image classification.

3.1.4 Compatibility with surveying data

The software should have options to import and process field data from GPS, total stations and handheld PDAs. Some GIS products have functions to connect to GPS devices and download data from them.

3.1.5 Presentation and output

The software must have the functionality to produce cadastral maps as required by the cadastral organization, including the required point and line symbology, additional map elements such as the legend, scale bar and north arrow, and support the printing or plotting on A0 format or custom paper size.

3.1.6 Database connection

For most purposes, it is more efficient to store geographic data in server-based geodatabases instead of in local file structures. When used for a considerable volume of map data, or if multiple users need simultaneous access to the same dataset, the software must support connections to directly access and edit map data stored in external databases.

3.1.7 WebGIS functionality

More and more desktop GIS products (proprietary as well as open source) are adopting the Open Geospatial Consortium (OGC) interoperability standards to access remote geographic datasets over the internet. With Web Map Service (WMS) support, datasets from web mapping servers can be displayed as images, while the Web Feature Service (WFS) gives users access to the raw geographic datasets. While few cadastre authorities distribute cadastre datasets through WFS as yet, this technology is expected to gain popularity in the coming years.

3.2 Open source desktop GIS products

A selection of open source GIS tools has been reviewed in the FAO Scoping paper on FLOSS (Pieper Espada, 2007), and the following sections focus on the new developments of these initiatives. Remarkably, a lot of recent OSG development seems to be concentrated in Spain and its autonomous regions. Kosmo and gvSIG are maintained by companies in Sevilla and Valencia, respectively, while the Axios editing tools for uDIG are being developed by a company based in Bilbao. There are many more open source GIS tools available (see OpenSourceGIS.org for an extensive list) but the products that are discussed here are considered most useful in land administration systems.

3.2.1 GRASS

The Geographic Resources Analysis Support System (GRASS) is probably the best known and oldest open source GIS tool. The development of GRASS was started in the 1980s by the US Army Corps of Engineers. GRASS was originally written as a raster image processing system, and vector analysis capabilities were added later. Designed as a UNIX program, GRASS works best on the UNIX-derived operating systems such as Linux. As for now, Windows users need to install Cygwin tools to operate GRASS. The GRASS developers are working towards the beta release of version 6.3 that will run natively on Windows as well as the UNIX and Linux operating systems. Although GRASS is an excellent raster GIS with advanced spatial analysis tools, it lacks some important editing tools for the maintenance of cadastral datasets and would be hard to customize for cadastre systems.

3.2.2 Quantum GIS

Quantum GIS (or QGIS for short) is under development since 2002 and provides a more user friendly alternative to GRASS. Thanks to the close cooperation between GRASS and Quantum GIS, GRASS functionality is available from within the QGIS application. GRASS layers can be edited directly without the need for conversion so that QGIS can be used as a frontend application to maintain GRASS datasets. Although most of the common raster formats are supported, QGIS does not have the image processing functions that GRASS has. A few new editing tools have been added to the 0.9 version. It is now possible to create multipolygons and polygons with holes or islands, but compared to gvSIG, JUMP and Kosmo the number of editing options in QGIS is still very limited.

3.2.3 uDIG

uDIG stands for User-friendly Desktop Internet GIS, and from all the desktop OSG products, this is indeed the one with the most internet functionality. Besides the tools for desktop GIS data management, it supports the geospatial web services WMS, WCS, and WFS including transactional WFS. The development of uDIG was started in 2004 by Canadian based Refractions Inc. Compared to other OSG, uDIG has little vector editing options but this will soon change.

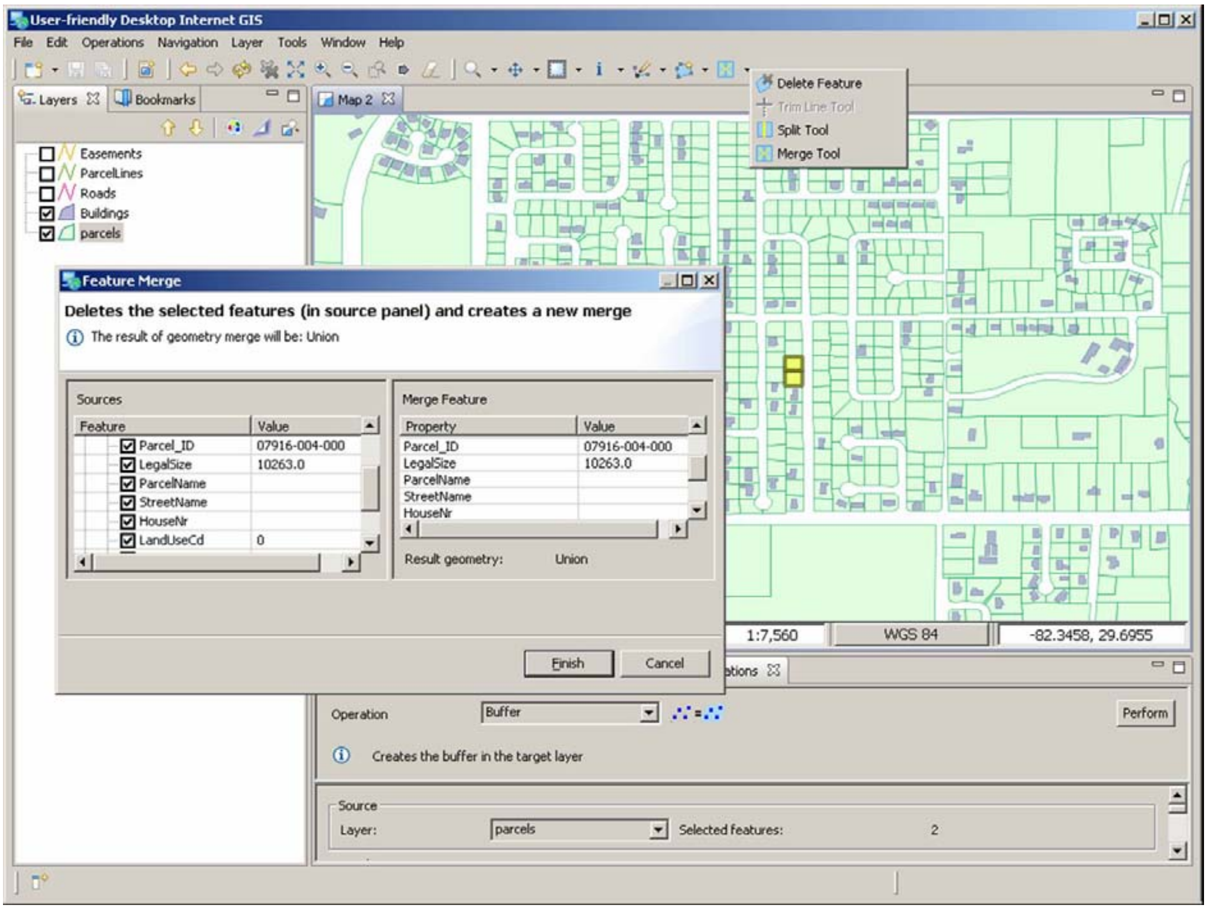

Figure 3-1: New editing tools for uDIG are being developed that lets users split and merge polygons

Recently, a Basque company called Axios has started to develop the needed vector editing and geoprocessing tools for uDIG on request of the Departamento para la Ordenación y Promoción Territorial (DOPT) in Basque Country, Spain (uDIG, 2008). Among the planned tools are splitting and merging of features, trim, buffer, intersect and other geoprocessing tools. A first experimental version has already been released and the source code can be downloaded from the uDIG website. With the availability of these important editing tools, new possibilities arise to use uDIG as a GIS base in land administration systems.

3.2.4 gvSIG

This is an open source GIS product developed in Spain by IVER Technologías in cooperation with the Valencian government and the Jaume I University of Castellón since 2003. The name gvSIG is a Spanish abbreviation that stands for *Generalidad Valencia Sistema de Información Geográfica*. Once accustomed to the interface, gvSIG is a user-friendly GIS product for which many translations are available. The combination of editing capabilities, platform independency and support for PostGIS as well as MySQL database connections makes gvSIG a highly useful GIS base for land administration systems. According to the gvSIG Desktop Roadmap (gvSIG, 2008) a topology extension that would allow users to apply topology constraints to spatial datasets is under development. More editing tools including cutting and merging of polygons are also planned to be released soon. In March 2008, a lightweight version of gvSIG has been released that can be used on mobile devices (PDAs). It supports shapefiles, ECW, WMS and images and is able to connect to GPS receivers. Currently, only the visualization of layers and the generation of GPS tracklogs and waypoints are supported, but functions to create and edit geometries are planned as well.

3.2.5 OpenJUMP

JUMP (JAVA Unified Mapping Platform) was initially developed in 2002 by Vivid Solutions Inc. on initiative of the British Columbia Ministry of Sustainable Resource Management and evolved into a platform independent GIS with strong editing capabilities. JUMP uses the Java Topology Suite (JTS) which implements the OGC Simple Features Specification for geometric operations. Compared to other open source desktop GIS, JUMP has quite advanced editing tools, including cut and merge polygon features. It can also check for basic topology errors such as self-intersecting polygons. JUMP has a warping function that can be used to rubber-sheet a vector layer using a bilinear interpolation method. Even though the editing and statistical functions are impressive and JUMP continues to be a very useful desktop GIS, there are down sides as well. JUMP has little support for coordinate systems, as it does not use the GeoTools library for projections. Problems with the memory allocation make it difficult to load and edit large map layers or PostGIS tables in JUMP. Apart from OpenJUMP, there is SkyJUMP, PirolJUMP and DeeJUMP all with a similar interface but each having its own additions. With the different versions and sub versions of JUMP it is hard to get a clear overview of its capabilities, but this maybe solved when a documented public version 1.2 of the OpenJUMP software is released. (The latest OpenJUMP release is the 1.2 Pre-Release from August 2007).

3.2.6 Kosmo

Kosmo is another version of JUMP which has been further developed by the Spanish company SAIG (Sistemas Abiertos de Informacion Geografica) since 2006. This company describes itself as a “service providing company”; its business is selling services for Kosmo rather than the software itself. Its clients are mainly government institutions that contract the company to develop additional functions for the software, which in turn will benefit the whole

Kosmo user community (SAIG, 2006). One major improvement compared to OpenJUMP is that Kosmo is integrated with the GeoTools library and supports coordinate transformations as well as the OGC Styled Layer Descriptor (SLD) specifications for layer symbols. Also the database connections are improved; Kosmo supports full read/write access to geographic data stored in PostGIS, MySQL and Oracle Spatial. With the important improvements to the performance and scalability, the Kosmo developers have turned this version of JUMP into a very usable desktop GIS with the only drawback that its software documentation is available in Spanish only.

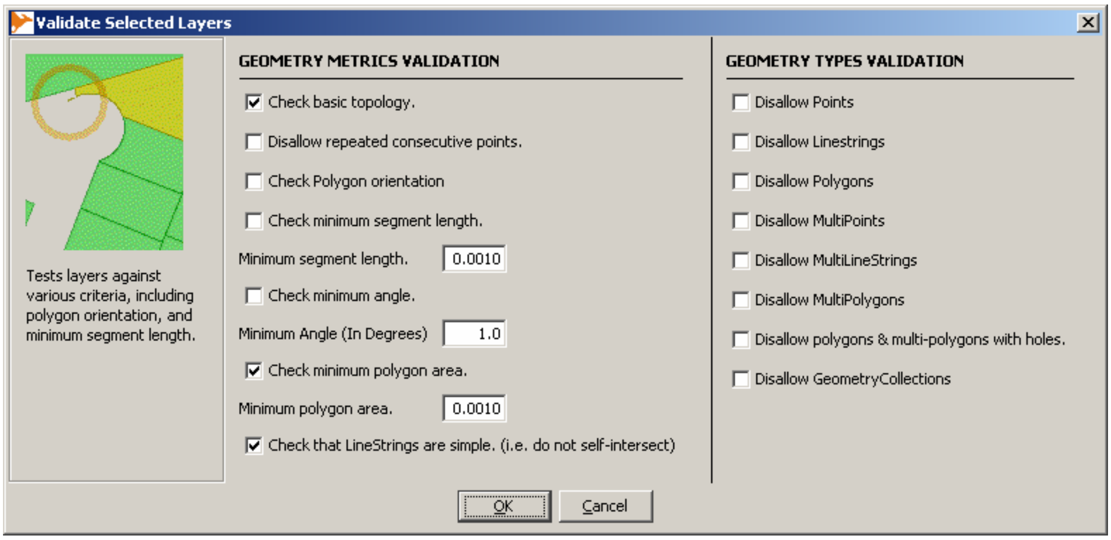

Figure 3-2: OpenJUMP and other products from the JUMP family include tools for topology checking

3.3 Open source desktop GIS products compared

Table 3-1 compares the editing and other standard features of the open source desktop GIS products that have been mentioned above. While this is by no means a complete overview of all the capabilities of these products, it compares the general GIS functions that would be required in a land administration system, focusing especially on the vector editing functions. Although some of these functions like polygonize, calculate area and vector overlays can also be handled on database level by PostGIS, vector creation functions, topological editing as well as splitting and merging of polygon features are considered essential desktop GIS functions in cadastre systems. All desktop OSG products listed here have the basic editing tools needed to create and maintain cadastral parcel boundaries as well as raster support to be able to display orthophotos or other imagery as a base for cadastral mapping. In most cases however, these tools must be customized to work efficiently in cadastre systems, for example to maintain history versions of modified boundaries.

Table 3-1: Comparison of open source desktop GIS products

PROPERTIES	GRASS 6.2.3	Quantum GIS 0.9.1	uDIG 1.1	gvSIG 1.1.2	OpenJUMP 1.2D	KOSMO 1.2
Type of product	Open source desktop GIS with raster, image processing and vector analysis functionality	Open source desktop GIS with vector and raster support, to browse and create map data	Open source internet oriented desktop GIS	Open source desktop GIS with CAD, vector and raster support	Open source desktop GIS for manipulating spatial features with geometry and attributes	Open source desktop GIS, derived from JUMP
License	GNU/GPL	GNU/GPL	GNU/LGPL	GNU/GPL	GNU/GPL	GNU/GPL
Website	http://grass.itc.it	http://www.qgis.org	http://udig.refractions.net	http://www.gvsig.gva.es	http://openjump.org	http://www.saig.es
Operating system	Unix, Linux, MacOSX (runs on Windows only with CygWin tools)	Unix, Linux, MacOSX and Windows	Windows, Linux, MacOSX	Windows, Linux, MacOSX	Windows, Unix, Linux, MacOSX	Windows, Linux
Supported vector formats	GRASS vector (native format), read directly Shapefile, PostGIS; can import TIGER, DGN, MapInfo and GML2	OGR formats (Shapefile, MapInfo MIF/TAB, Spatial Data Transfer Standard catd.ddf, GML) PostGIS, GRASS	Shapefile, PostGIS, OGR vector formats	Shapefile, dgn, dxf, dwg, PostGIS, WFS vector layers	JML (OpenJUMP GML) Shapefile, WKT Plugins for DXF, CSV, MIF, GeoConcept and PostGIS	Shapefile, dxf, dwg, csv, PostGIS
Vector creation	Point, line, boundary, centroid (v.edit module)	Point, line, polygon, multipolygon, centroid	Polygon, line, point, rectangle, ellipse (also polygon with holes)	Point, multipoint, Line, arc, polyline, polygon, rectangle, circle, ellipse	Point, line, polygon (also polygon with holes) rectangle, multiPoints, multiPolygon, multiLine	Point, Line, Polygon (also polygon with holes), rectangle, circle, arc
Topological editing	Add/delete/move vertices	Add/delete/move vertices	Add/delete/move vertices	Add/delete/move vertices	Add/delete/move vertices	Add, delete and move vertices; merge multiple vertices into one
Cut and merge polygons	No	No	Under development (Axios tools)	Under development	Yes	Yes
Other editing functionality	Merge and break lines; copy/move/delete/ flip vector features; Dissolve polygons Trim/extend lines	Move line, split line (GRASS layers)	Tools for clip, trim lines are under development	Move, rotate or flip features, clip, dissolve	Move, rotate features, split lines	Extend / trim lines, draw parallel and perpendicular lines, rotate features, clip, dissolve
Buffer (around point, line or polygon)	Yes (v.buffer)	Only with PostGIS layers	Under development	Yes	Yes	Yes
Vector Overlays (Union, Intersect, Subtraction)	Yes	No	Under development	Yes	Yes	Yes
Spatial queries on vector layers	Yes (v.distance)	No	Under development	Yes (nearest neighbour / contained in)	Yes (intersects, contain, assign data by location)	Yes
Convex hull	Yes	No	No	Yes	Yes	Yes
Field calculator	No	No	No	Yes	No	Yes
Calculate area of polygons	Yes (area.c)	One by one with Identify tool	No	Yes	Yes	Yes
Polygonize (convert lines to polygons)	No	No	No	No	Yes	Yes

PROPERTIES	GRASS 6.2.3	Quantum GIS 0.9.1	uDIG 1.1	gvSIG 1.1.2	OpenJUMP 1.2D	KOSMO 1.2
Snapping tools	Snap function to snap one line to another while digitizing.	The software allows the user to set the snapping tolerance and snap to nodes and vertices	Snap radius can be set to snap to nodes and vertices.	The software allows users to set the snapping tolerance and snap to nodes and vertices. Snapping to elements from different layers is also possible.	Vertices can be snapped to the reference grid, as well as to other vertices or lines.	Snap tolerance can be set to snap to lines or vertices, or snap to a grid
Topology tools	Module v.build to build topology.	No	With the validation plugin, vector layers can be checked for correct geometry, self-intersecting or overlapping lines and dangling nodes.	Topology extension is under development	Topology validation tool to check for valid geometry	Topology validation tool to check for valid geometry
Raster support	More than 40 supported raster formats (through GDAL)	TIFF, ERDAS (.IMG) ArcInfo ASCII Grid SDTS (.ddf) DTED Elevation raster (.dt0) USGS DEM AIG GRASS	TIFF, JPG, GIF	TIFF, JPG, ECW, MRSID	TIFF, GIF, JPG, ECW and PNG	TIFF, PTIF, BMP, JPB, GIF, PNG, MRSID, ECW
GPS tools	Import waypoints, routes, and tracks from a GPS receiver or GPS download file into a vector map (v.in.gpsbabel)	Supports GPX format, download from/ upload to GPS through GPSBabel	No	gvSIG Mobile Pilot can connect to GPS receivers and generate tracks and waypoints in GPX format	No	No
Database / SDBMS support	DBF, ODBC, MySQL, PostGIS/PostgreSQL SQLite	PostGIS/PostgreSQL	PostGIS, OracleSpatial, ArcSDE and MySQL	PostGIS, MySQL	Plugins for PostGIS, ArcSDE	PostGIS/PostgreSQL, MySQL, Oracle Spatial
Programming language	ANSI C	C++	Java	Java	Java	Java
Development platform / class libraries	Software components depend on multiple libraries	Qt with PROJ4, GEOS, SQLite, GDAL/OGR and other libraries	Eclipse RCP with GeoTools libraries	Eclipse with GeoTools and JTS libraries	Java Topology Suite (JTS)	GeoTools, JTS
Command line / Menu bar	Both	Menu bar	Menu bar	Both	Menu bar	Menu bar
Interface language	Translated into 20 languages, more coming	Translated into 26 languages	English, German, Spanish, French	Valencian, Spanish, Galician, English, Czech, German, Basque, French, Italian, Portuguese, Chinese	English, Finnish, Portuguese, French, Italian, German, Spanish	English, Spanish, Portuguese, Russian, German, Italian
GML	Yes	Yes	Yes	Yes	Yes	No
WMS	Yes (r.in.wms)	Yes	Yes	Yes	Yes	Yes
WFS	Yes (v.in.wfs)	Yes (WFS plugin)	Yes	Yes	Yes	Under development
WFS-T	No	No	Yes	No	No	No

3.4 Server-side OSG tools and web GIS services

When it comes to web servers and server operating systems, the use of open source software has already been widely accepted. Research shows that two-thirds of European companies choose open source systems like Apache, Tomcat and Linux over proprietary alternatives (Ghosh, 2006). Also land administration systems can benefit from the use of open source server software. Especially in the area of internet mapping and web enquiry systems, OSG products are increasingly popular.

GeoServer, MapServer and Deegree are open source map server products focussing on internet mapping applications using OGC webGIS standards. These OGC interoperability standards such as Web Map Service (WMS), Web Feature Service (WFS) and Transactional WFS (WFS-T) allow for the cross-platform exchange of geographic information over the internet. Using these standards, map data stored in Oracle Spatial, PostGIS or ArcSDE databases can be accessed over the internet with a standard web browser or GIS client software. With WMS, map data can be accessed and displayed as an image that can be overlaid with GIS data from other data sources to produce composite maps. With WFS, users can access the actual geographic features in vector format, while WFS-T allows for creation, deletion and updating of features. MapServer, GeoServer and Deegree are server-based “map engines” to display spatial data (maps, images or vector data depending on the OGC web service) over the internet to users based on their requests. In his State of Open Source GIS, Ramsey (2007) states that *MapServer is easily the most successful open source GIS project to date*. *It supports more input data sources than proprietary products, has higher performance and is simpler to install and set up.* And indeed, MapServer has proved to be a very mature and reliable product to distribute maps from GIS data sources over the internet through the WMS, WCS and other OGC interoperability standards. GeoServer and Deegree are more recent projects built with Java technology. While comparable to MapServer in many ways, GeoServer and Deegree go further by supporting transactional WFS services, allowing users to insert, delete and modify geographical data at the source from remote locations through the internet.

The government of Bavaria, Germany uses MapServer to give citizens access to public geographic data through WMS as part of their SDI and e-Government policy. Also cadastre data is available through the Bavarian GeodatenOnline webportal, which is built with open source software and uses PostgreSQL with PostGIS as backend database (Bayerische Vermessungsverwaltung, 2004-2008). Another good example of the use of open source software (MapServer) and the OGC interoperability standards in land administration systems can be found on the geoportal of the Spanish cadastre. Spain has a centralized cadastre that covers the whole country except for Navarra and Basque Country that have their own cadastre system (Dirección General del Catastro, 2005-2008). On this virtual cadastre office (OVC), users can access cadastral datasets through OGC web services. MapServer was chosen for its complience with OGC standards, the compatibility with the technology used by the DGC and its stability (Cano et al, 2006). The OVC offers different services for different kind of users; WMS data is publicly available for all users while the use of WFS is restricted to registered users. A WMS request to the OVC could be for example:

```
http://ovc.catastro.meh.es/Cartografia/WMS/ServidorWMS.aspx?
SERVICE=WMS&SRS=EPSG:23029&REQUEST=GETMAP&bbox=511950,4662900,
512150,4663100&width=756&height=756&format=PNG&transparent=No&
layers=catastro
```

This request would result in a map in the image format PNG. Other possible supported formats are jpeg, tif, gif and bmp (Conejo, 2007). A WFS request to the Spanish OVC could be for example:

```
http://ovc.catastro.meh.es/Cartografia/WFS/ServidorWFS.aspx?
service=wfs&version=1.0.0&request=getfeature&typename=parcela&
bbox=443826,4476055,443990,4476150
```

This would return a GML resultset with full geometry and feature attributes of the parcel layer for a specific area bounded by the coordinates as defined in the bounding box.

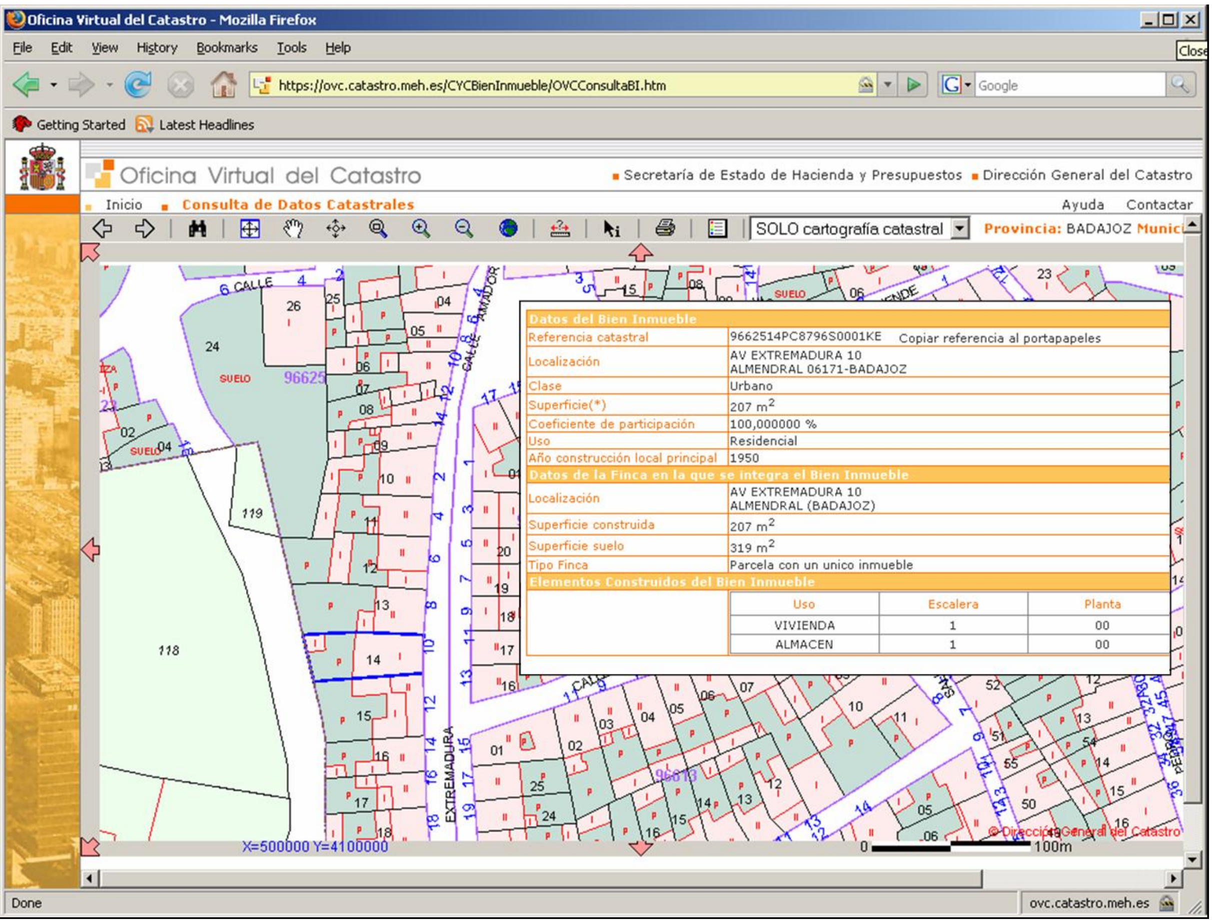

Figure 3-3: The Spanish cadastre uses MapServer and WMS to give users public access to cadastre data

With the web services that the OVC provides, the Spanish cadastre follows the INSPIRE principles to provide public access to spatial datasets that are collected by the government, and sets a good example of the use of server-side OSG tools and open GIS standards.

4. CONCLUSIONS

The recent developments in OSG are encouraging. With the added editing tools for uDIG, the promised topology extension for gvSIG and the improvements that the Kosmo developers have made to the JUMP software core, new possibilities are opening up to use these products in land administration systems. When the basic editing requirements for the creation and updating of land parcel polygons are fulfilled, these desktop OSG can be used in combination with the topology functions of PostGIS to form the GIS base of a low-cost but robust cadastre system. Cadastral datasets can be stored and maintained in PostgreSQL with PostGIS on a Linux server, or even on a normal PC. For distributing cadastral information over the internet to customers, an internet mapping server like MapServer, GeoServer or Deegree can be used. All these products are easy to download, install and use. Compared to proprietary equivalents, the open source products tend to use less memory and disk space, and they can be installed on older and cheaper hardware which helps to further reduce the overall costs of the system.

The software must of course be customized to the local requirements of land administration, but the same is true for proprietary software: there are no out-of-the-box solutions for land administration systems. Customization and localization are important aspects of building land administration systems. Besides the obvious financial benefit, the use of open source software tools gives developers of such systems the advantage that they *can* be customized to reflect the local language and culture of land registration.

There are certainly other useful OSG tools that have not been mentioned here. Technical developments are going fast, and the progress on projects such as ILWIS Open and TerraView should be monitored for their potential use in land administration systems. All open source GIS tools that have been described here are available free of charge. With the recent advances in vector editing and other GIS functions, these OSG tools hold the promise that also in countries where financial resources are limited, the development of land administration systems can be affordable.

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BIOGRAPHICAL NOTES

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