

Free and Open Source GIS Software for Building a Spatial Data Infrastructure

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Abstract The implementation of Spatial Data Infrastructures (SDIs) for governments and companies is a task that has gained ample attention in recent years. Different categories of spatial software such as desktop GIS, server GIS, web map servers, spatial database management systems, web map development toolkits, etc., are required to realize the software components of an SDI. We catalogue a (selected) variety of free and open source projects that develop and maintain spatial software that fit within these categories. Our analysis reveals that for all categories of software used in SDIs a free software product is available. This enables adopters to implement an SDI on a limited financial budget, and allows the distribution of a proven SDI architecture without legal constraints. Our software evaluation shows that free and open source solutions support a wide range of industry standards that ease interoperability between SDI components.

1 Introduction

Over the past decade government organizations at provincial, regional, national and international levels, as well as non-governmental organizations and large companies, have been working on the implementation of Spatial Data Infrastructures (SDIs) - with the objective of easing access to spatial data for a wide range of users [1,2]. For instance, in Canada alone 93 new spatial portals and systems for spatial data dissemination have been built, and 251 new datasets published using GeoConnections¹ funding between the years 2005 and 2009 [3]. Building an SDI requires a range of software which may depend on the SDI participants' perspective: geospatial data provider, geospatial service provider, or geospatial data user. To support these ongoing implementation efforts we will (i) give an overview of the categories of software required, and (ii) list free and open source projects that develop and maintain such software. In particular, with this summary of free software projects we wish to aid persons charged with building and maintain-

¹ GeoConnections is a Canadian program that aims to make location-based data and technologies broadly accessible to decision makers (see www.geoconnections.ca).

ing SDIs by pointing to suitable candidates from the free software ecosystem that we believe are useful for the implementation of an SDI. We have chosen to focus on Free and Open Source Software (FOSS) as we believe that these solutions will further the implementation of SDIs in developing countries, government and industry, because of their ease of distribution, and because of their conformance to interoperability standards.

To our knowledge there have only been two earlier publications on the topic of FOSS for SDIs; Reid and Martin [4] and May et al. [5]. However, both were published several years ago, and there has since been considerable development in the free software community – as such we believe an update is warranted.

We will start the overview by introducing the components of an SDI, summarize the technical standards used to distribute and process spatial data, and identify the spatial software categories that are required to build an SDI. Subsequently we will introduce into free software terminology and briefly review FOSS literature that discusses free spatial software. Finally, we will catalogue, non-exhaustively, free spatial software projects that develop software that can be used in SDIs. We note, that we have decided to only list the projects, without description, due to the large number of projects – and space constraints.

2 Spatial Data Infrastructures

Before mass use of the Internet and its technologies, and still today to a large extent, spatial data for a particular location have been stored in different physical locations, and often using different standards or formats. This makes it difficult for a potential user to access and utilize the data. Smits [6] has described this situation as “[...] islands of data of different standards and quality...”. Potential users of these “islands of data” might be organizations that cannot afford to acquire data on their own, or need data from outside their jurisdictions [1]. Hence, the primary objective for creating an SDI is to provide these potential users access to (spatial) data stored somewhere else [28], i.e., the sharing of data, to save resources, time and effort, by avoiding the duplication of effort required to acquire and maintain the data [1].

Besides the technical components that connect data ‘islands’ via the Internet, other aspects such as licensing agreements, data transfer standards, and data access policies must also be put in place to ensure consistent and reliable access. Consequently, a spatial data infrastructure is not only a technical facility, but a complete framework that includes political, technical, business and social aspects. From the diverse literature on SDIs [1,2,6,7,8,9,10] we found it useful to distinguish the following five components:

- (i) Spatial Data (or spatial information),
- (ii) Technologies, i.e. hardware and software,
- (iii) Laws and Policies,

- (iv) People, i.e.: data providers, service providers, users, and
- (v) Standards for data acquisition, representation and transfer.

A definition for SDI given by Kuhn [8] includes more or less all of these components (emphasis from the original text):

An SDI is a **coordinated** series of **agreements** on **technology** standards, **institutional** arrangements, and **policies** that enable the **discovery** and **use** of geospatial information by users and for purposes **other** than those it was created for.

2.1 GIS software needs in SDIs

A Spatial Data Infrastructure should enable the discovery and delivery of spatial data from a data repository², ideally via one or more web services. Additionally, it is often desirable that the data provider is able to (remotely) create and update spatial data stored in a repository. Hence, the basic software components of an SDI consists of (i) a software client that can display, query, and analyse spatial data, (ii) a catalogue service for the discovery, browsing, and querying of metadata or spatial services, spatial datasets and other resources, (iii) a spatial data service that enables the delivery of the data via the Internet, and/or processing services such as datum and projection transformations, (iv) a (spatial) data repository, and (v) GIS software (client or desktop) that permits the creation and maintenance of data (Fig. 1). The catalogue service (item ii above) functions in a similar manner to analogue directories such as the Yellow Pages. The extent of processing services (iii above) is somewhat unlimited, but transformation services are generally fundamental to a distributed system.

2.2 Important technical standards for spatial data distribution

Several technical standards defined by the Open Geospatial Consortium (OGC, opengeospatial.org) and the International Organization for Standardization (ISO 19xxx series, iso.org) play an important role in the dissemination and processing of spatial data. In general, these standards describe communication protocols between data servers, servers that provide spatial services, and client software, which request and display spatial data. In addition, they define a format for the transmission of spatial data. We identify the following OGC standards that are required to build an SDI:

² For our purposes a data repository is a collection of spatial datasets, that may be stored in one or more spatial databases, on one or more physical servers, i.e., a data warehouse. We assume that the repository is integrated and non-volatile.

- OGC data delivery standards: Web Mapping Service (WMS), Web Feature Service (WFS) and its transactional equivalent (WFS-T), and the Web Coverage Service (WCS);
- OGC data format standards: Simple Feature Standard (SFS), Geography Markup Language (GML), Keyhole Markup Language (KML);
- OGC data search standards: Catalogue Service (CSW), Gazetteer Service (WFS-G); and
- Other OGC standards: Web Processing Service (WPS), Coordinate Transformation Service (CTS), Web Terrain Service (WTS), Styled Layer Descriptor (SLD), Symbology Encoding (SE), Web Map Context (WMC).

The ISO Standard 19115 (Geographic Information – Metadata) is also important as it defines a schema for describing spatial data, and ISO 19119 (Geographic Information - Services) defines how spatial data and services should be described so that they are able to be searched by catalogue services (such as OGC's Catalogue Service). Specifications developed by the World Wide Web Consortium (W3C) for data dissemination such as HTML, XML, SVG, SOAP, WSDL, etc., should also be considered (see Chapter 7 of the SDI Cookbook [9]). Further information on applicable and implemented standards can be found in [9,10,11].

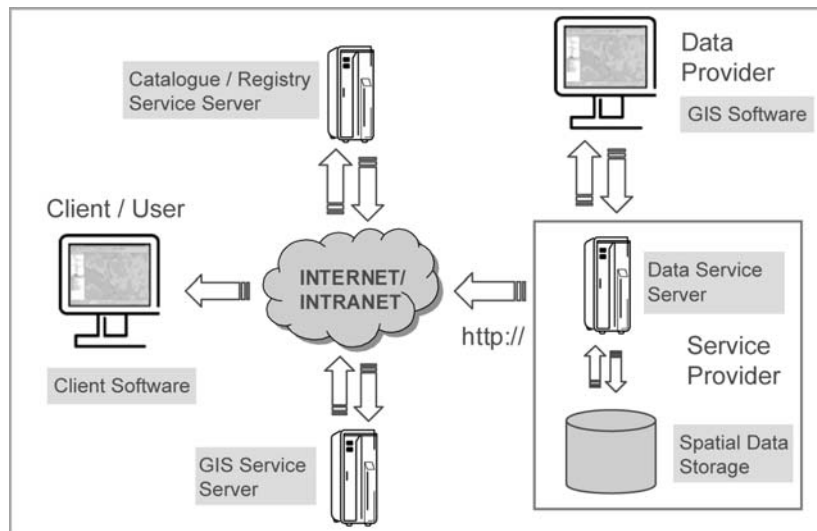


Fig. 1 Software needs of an SDI.

3 Free and open source spatial software

Defining terms: free and open source - Software that is called ‘*Free Software*’ or ‘*Free and Open Source Software*’ (FOSS) is covered by a specific type of software license. This license needs to grant the software user at least the following four freedoms: (1) the freedom to run the program, for any purpose (e.g., no matter if for educational or business purposes) (2) the freedom to study and adapt the program for one’s own needs, (3) the freedom to redistribute the software, and (4) the freedom to improve the software and to release these improvements to the public (see www.gnu.org/philosophy/free-sw.html). In this sense “*free*” takes on concepts of the public domain such that there are no rights to exclude. Hence, software that is (i) gratis, i.e. free-of-cost, and (ii) permits viewing of the source code does not automatically qualify as “free and open source” software. If the user’s rights include the right of independent use, of modification, and of free distribution — only then — can the software be called “free” and “open source” software. With respect to this definition a distinction between the categories of free/gratis vs. commercial/paid for software is not entirely correct, since the freedoms outlined above do not prohibit a developer from attaching a cost to the distribution and support of “free software”. For a discussion of free software licenses we refer the reader to Johnson [12], the Free Software Foundation web pages (fsf.org), and Steiniger and Bocher [13], who also discuss three common misconceptions of the General Public License (GPL). In our software review, we included only software that comes with licenses that grant the four freedoms mentioned above.

GIS software categories and literature on free GIS - Several categories of GIS software have been identified by Steiniger [14,15]. The classification includes: (i) *desktop GIS*, used for data creation, editing, analysis and map generation; and (ii) *Spatial Database Management Systems* (Spatial DBMS) that are used for the storage of data; (iii) *web map server* for the delivery of map like representations over the Internet; (iv) *server GIS*, that are used to remotely process, e.g., analyse, spatial data; (v) *web GIS clients*, to display and query spatial data stored at remote locations that are only accessible via Internet or intranet; (vi) *mobile GIS*, which are most often used for data acquisition in the field; and finally (vii) *GIS libraries and extensions*, which provide special functions that can enhance standard (desktop) GIS capabilities, or be used to build customized GIS applications, including web mapping applications.

Reviews of Free and Open Source Software for GIS (FOSS4GIS) and its utility have become more common over the last three years as several free software solutions have matured to the point that they are able to replace proprietary software. An early assessment of FOSS4GIS focusing on SDIs was completed by Reid and Martin [4], who concluded in 2001 that there was great potential for the use of FOSS4GIS solutions that incorporated SDI components. FOSS4GIS software re-

views not related to SDIs but rather environmental GIS applications have been completed by Jolma et al. [16] and Steiniger and Hay [15]. Ramsey's [17] general review of FOSS4GIS projects, Sanz-Salinas and Montesinos-Lajara [18] summary of major FOSS4GIS projects, and Steiniger and Bocher's [13] as well as Donnelly's [27] recent evaluation of FOSS4GIS desktop projects may also be of interest to SDI implementers.

4 Free and open source spatial software for SDIs

In the previous sections we have outlined the types of GIS software and the major software components that exist in a general SDI architecture. For the discussion below we have combined those categories and arranged the discussion as follows: (4.1) SDI server software: (4.1-A) web map servers (4.1-B) server GIS; (4.2) SDI spatial data storage: Spatial Data Base Management Systems (Spatial DBMS); (4.3) SDI registry/catalogue and metadata software; (4.4) SDI client software: (4.4-A) desktop GIS clients, (4.4-B) web-GIS development toolkits (see Fig. 2).

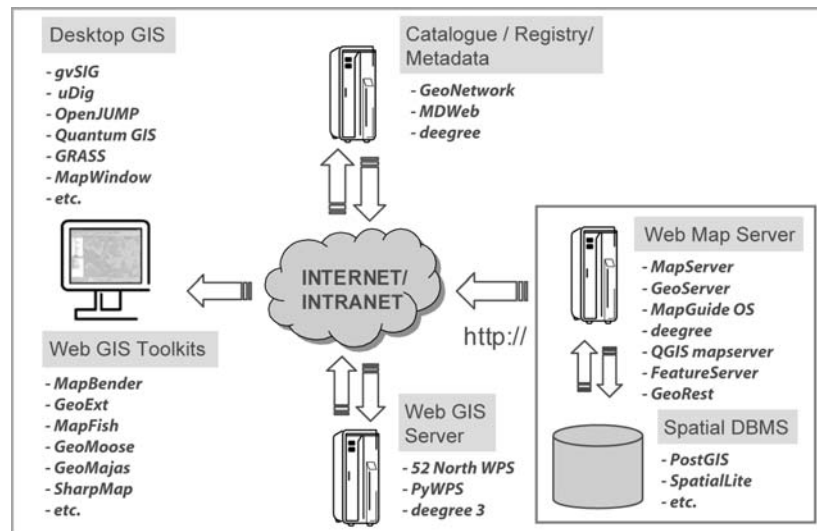


Fig. 2 FOSS4GIS Software that can be used in an SDI.

Our review below aims to focus only on the more established projects. For some categories we will also mention software under development if we believe the project could attract a wider user group. Due to page limits we will only list the software projects and not describe them in detail – and instead refer the interested

reader to the related project web pages and Sanz-Salinas and Montesinos-Lajara [18]. However, we try to give a general assessment for the software categories with respect to software advancement and use in comparison to proprietary software, and list in Table 1 the supported OGC/ISO standards for selected software.

4.1 SDI Server software

In the following we distinguish between two different categories of server software, web map and web-GIS servers, owing to their different usage (see [14,15]).

A - Web Map Servers for serving data and images – Web mapping services, i.e. servers, usually serve spatial data based on three OGC standards: WMS (or ISO 19128: 2005, Geographic Information – Web Map Services) for the display of maps as image, WFS for vector data, and WCS for raster data. Web map servers rarely allow interaction with the data in terms of processing or editing. However, if standards such as the OGC WPS (processing) and OGC WFS-T (editing) are implemented, then this is possible. The two best-known software distributions are (UMN) MapServer (mapserver.org) and GeoServer (geoserver.org). Both solutions are comparable to similar proprietary solutions with respect to their functionality. Autodesk also offers a widely adopted open source web map server, MapGuide Open Source (mapguide.osgeo.org), which has evolved out of Autodesk's proprietary MapGuide 6.5 software. A fourth server software, with a strong European user base, is the deegree server/application framework offered by lat/lon GmbH (wiki.deegree.org). deegree has been the reference implementation for several OGC standards [11].

All four web server products have been released for several years and are widely used in SDI settings. Often they have been the preferred choice, when compared to proprietary offerings, e.g. [19,20]. We also note the 2009 release of QGIS mapserver by the Quantum GIS desktop community (karlinapp.ethz.ch/qgis_wms). Finally, there are two REST based approaches that warrant mention, FeatureServer (featureserver.org), and GeoRest (code.google.com/p/georest). In a RESTful style service everything is treated as a resource and representations of resources can be uniquely addressed by a universal resource identifier (URI). Both systems offer WFS capabilities and provide various contemporary web formats such as GeoJSON, KML and GeoRSS.

B – Web-GIS Servers for data processing – These solutions are distinct from web map servers as they do not provide web mapping services, but rather they expose GIS processing functionality that is typically offered by desktop GIS software - for example data analysis and transformation services. To use the processing functionality the software should support the OGC WPS standard (or ISO

19119: 2005, Geographic Information – Services), which in turn acts as our selection criterion for this listing.

One solution that implements the WPS standard is 52N WPS software by 52° North (52north.org). Spatial analysis, i.e. processing functions, provided by the 52 North software stem from the Sextante project. 52 North also distributes two client plug-ins for the free desktop GIS' uDig and JUMP / OpenJUMP. A further implementation of the WPS standard for server-side use is part of the deegree 3 framework (wiki.deegree.org). The software PyWPS implements the OGC WPS standard (pywps.wald.intevation.org) and enables access to a wide range of analysis functions for the desktop GIS GRASS. Finally, the new ZOO Project (zoo-project.org) also aims to develop software to access and distribute WPS services.

4.2 SDI Data storage software: spatial DBMS

Spatial Database Management Systems (DBMS) are usually not developed as a software solution on their own, but rather developers add spatial capabilities to existing free DBMS. The product with the largest user base is probably PostGIS (postgis.refractory.net). PostGIS adds spatial data types and analysis functions to the FOS database PostgreSQL (postgresql.org). PostGIS is currently used in high demand installations, for example by the French National Mapping Agency (IGN France), and it provides the most complete implementation of OGCs Simple Feature Specification (OGC SFS) of any FOSS DBMS solution. Comparisons with proprietary Spatial DBMS, such as Oracle 10g Spatial, show that PostGIS is a comparable alternative when considering functionality, robustness, support and price (see [21]).

Two other FOSS DBMS projects include spatial data capabilities. They are the MySQL Spatial extension (mysql.com), which adds spatial support to MySQL, and the SpatialLite project for SQLite (gaia-gis.it/spatialite). Currently MySQL Spatial provides a basic implementation of OGCs SFS for SQL standard, but query and analysis operations utilize (Minimum) Bounding Rectangles instead of true geometries. Hence, operations have lower precision and may not be useful for everyone [22]. SpatialLite realizes conformance to the OGC Simple Features Specification by utilizing the functionality of the GEOS geometry library (trac.osgeo.org/geos).

In addition to the above, there are a number of projects adding spatial support to DBMS, that include (i) Hibernate (hibernatespatial.org), (ii) H2 DBMS (see the websites geoserver.org, orbisgis.org, and hatbox.sourceforge.net), and (iii) INGRES (community.ingres.com/wiki/IngresGeospatial). Also CouchDB (couchdb.org, [23]) and MongoDB (mongodb.org, [24]) have been used for storing spatial data. Both projects offer a JSON (JavaScript Object Notation) document-oriented database with query and indexing capabilities. However, there are cur-

rently no spatial extensions that we are aware of that enable native spatial queries in these ‘NoSQL’ database implementations.

Table 1 Selected OGC standards supported by some of the GIS software mentioned.

Software Category	Software	Selected Supported OGC & ISO Standards
Web Map Server	MapServer	WMS, WFS, WCS, SLD, WMC, GML
	GeoServer	WMS, WFS, WFS-T, WCS, SLD, GML, KML
	Deegree 3	WMS, WFS, WFS-T, WFS-G, WCS, WMC, SLD, GML, WPS, CS-W
Registry/ MetaData	Map Guide Open Source	WMS, WFS
	QGIS Mapserv	WMS, SLD
	GeoNetwork	CS-W, ISO 19115:2003, Geographic Information - Metadata
	Deegree 3	see above, ISO 19115, ISO/TS 19139:2007, Geographic Information – Metadata – XML Schema Implementation, ISO 19107: 2003, Geographic Information – Spatial Schema
	CADMEdit,	ISO 19115
	MDweb	ISO 19115, ISO 15836: 2003, Information and Documentation – The Dublin Core Metadata element set)
	Desktop GIS ²	Quantum GIS
	OpenJUMP	WMS, WFS ¹ , SFS, GML, KML ¹ , SLD, WFS-T ¹ , WPS ¹
	gvSIG	WMS, WFS, WFS-G, WCS, GML, KML, CS-W
	uDig	WMS, WFS, WFS-T, SFS, GML, SLD, WPS ¹
	MapWindow	WMS ¹ , WFS ¹
	GRASS	WMS, WFS, GML, WPS ¹

¹Supported via plug-in; ²After writing this article ILWIS Open 3.7 received WMS support.

4.3 SDI Registry/catalogue and metadata software

In our search for software falling under the registry/metadata category we found four projects. Three projects provide software to setup a server that functions as “yellow pages” like inventory for spatial data. The first project is GeoNetwork Opensource (geonetwork-opensource.org) funded and used by several large agencies including the Food and Agriculture Organization of the United Nations, the World Food Programme, the United Nations Environment Programme, and the United Nations Office for the Coordination of Human Affairs. MDweb (mdweb-project.org) is a project initiated by research institutes in France and the software is used in several environmental projects and institutions. The deegree framework

(wiki.deegree.org) also provides metadata services for the creation, storage, query, retrieval and display of metadata. The fourth software is not a server-based catalogue software, but a metadata editor for desktop computing: CatMDEdit (catmdedit.sourceforge.net). The software allows creation and editing of metadata for several types of GIS file formats and is used by a number of public agencies such as the EUs Statistical Office EuroStat, the National Geographic Institute of Spain and the French National Mapping Agency.

4.4 SDI Client software

A – Desktop GIS clients for data update and analysis - Desktop GIS can be considered the work horse of GIS software. As such, there are a number of FOSS projects that develop and maintain desktop GIS. Recent reviews [13,15, 27] identify eight mature FOSS desktop GIS. We use the term “mature” to refer to software solutions that offer extensive software functionality, software support, and an international focus driven by both user and developer communities. In order to use desktop GIS in an SDI context the software should provide at least OGC WMS capabilities to ensure that it can act as an SDI client. As not all eight desktop GIS have WMS support our list is reduced to seven: (1) GRASS GIS (grass.osgeo.org), (2) Quantum GIS (qgis.org), (3) uDig (udig.refractorions.net), (4) OpenJUMP (openjump.org), (5) MapWindow GIS (mapwindow.org), (6) gvSIG (gvsig.org), and (7) ILWIS Open (52north.org). More details on the capabilities of these software can be found in [13].

Besides these projects some more local or specialized projects exist, e.g., the KOSMO project with a focus on Spanish users (opengis.es). In addition, several newer projects can be found that currently have small user and developer communities, e.g., iGeoDesktop (deegree.org), OrbisGIS (orbisgis.org), and Puzzle GIS (puzzle-gis.codehaus.org).

B – Web-GIS development toolkits for browser-based clients – As an alternative to desktop GIS software, sometimes referred to as a *thick* client, it is becoming more common to make use of a web browser-based *thin* client to display (and query) data. However, to construct a standard web browser for the display of spatial data requires additional functionality on either the client, the server, or both. Several toolkits are available that aid the development of web map pages - or complete spatial data portals.

A simple web map page contains usually only a data viewer with no advanced query or styling functions, although these can be added. To incorporate a simple interactive map the OpenLayers library (openlayers.org) provides an OGC WMS / WFS compatible spatial data viewer. The project OpenScales (openscales.org) provides another option with its Adobe Flex-based viewer. Several other map viewer projects exist or have existed, e.g., ka-Map, Chameleon, ModestMaps and

MapBuilder, but several of those projects joined the OpenLayers project [see 25]. Hence, there has been an increase in the adoption and development of OpenLayers recently. Two more viewers should be mentioned. The first is SLMapView (slmapviewer.codeplex.com), which provides a Microsoft Silverlight interface for MapServer users. The second viewer, MapBender (mapbender.org), is not only a viewer but a web mapping framework that provides functions for managing spatial data services as well, i.e., MapBender could be used to create an SDI portal.

Several development toolkits exist that include not only a viewer (often OpenLayers) but also other tools that help to build web map pages for display and query (or even editing) of spatial data. Projects that provide such frameworks include: GeoMajas (geomajas.org), GeoExt (geoext.org), GeoMoose (geomoose.org), MapFish (mapfish.org), Mapstraction (mapstraction.com), and SharpMap (codeplex.com/SharpMap). If more complex web applications are to be developed, then it is also recommended that developers consider the use of Google's Web Toolkit (gwt.google.com) and Google Gears (gears.google.com). GeoTools (geotools.org) should also be considered to realize server side like GIS functionality and spatial data access.

6 Concluding remarks

Our software review shows that for all categories of GIS software required for the implementation of an SDI, a free and open software product is available. A more detailed examination also reveals that several free products are able to compete with proprietary software, in particular the web map server projects, the spatial DBMS PostGIS, and the data viewer OpenLayers. Indicators for competitiveness in these instances are the number of “real-world installations” and their use in high-demand environments. However, if an organization chooses to implement an SDI using FOSS, then the appropriateness of FOSS projects and software need to be assessed. Key criteria for such an assessment are: (i) functionality, (ii) support of common data distribution standards (e.g. OGC, ISO, CEN standards), (iii) supported platforms (Windows vs. Linux, etc.), (iv) software reliability, (v) options for customization, (vi) distribution costs, (vii) installation and maintenance effort (incl. costs), (viii) training and support options including pricing [26]. For a first evaluation of the software it is recommended that adopters make use of GIS distribution packages (for Linux), such as HostGIS (hostgis.com), or Virtual Machine GIS installations, such as GIS VM (gisvm.com) and OSGeo's Arramagong (download.osgeo.org/livedvd/).

The licenses used by free and open source products ensure a low acquisition cost (typically no cost) for the software itself, and ensure that the software is customizable and adaptable to the SDI context. Hence, and with respect to the latter point, free and open source software often implement a wide set of (OGC) standards, and if not, at least permit the implementation/addition of components that

are OGC/ISO standard compliant. The use of open source licenses allows an adopter to deploy SDI components to other locations at no additional cost, e.g., for horizontal scaling of a system. Finally, we note that helpful user and developer communities exist, and that support and maintenance options are offered by various companies, which are similar to those currently offered by proprietary software vendors. In summary, we see that FOSS4GIS software can provide a viable alternative to proprietary products - and we hope that our review helps to assess the utility of FOSS4GIS for SDIs.

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