The Academic SDI—Towards Understanding Spatial Data Infrastructures for Research and Education

Serena Coetzee, Stefan Steiniger, Barend Köbben, Adam Iwaniak, Iwona Kaczmarek, Petr Rapant, Antony Cooper, Franz-Josef Behr, Govert Schoof, Samy Katumba, Rumiana Vatseva, Kisco Sinvula and Harold Moellering

Abstract The demand for geospatial data across different disciplines and organisations has led to the development and implementation of spatial data infrastructures (SDI) and the theory and concepts behind them. An SDI is an evolving concept about facilitating and coordinating the exchange of geospatial data and

S. Coetzee (✉) · A. Cooper · K. Sinvula
Department of Geography, Geoinformatics and Meteorology,
Centre for Geoinformation Science, University of Pretoria, Pretoria, South Africa
e-mail: serena.coetzee@up.ac.za

A. Cooper
CSIR Built Environment, Pretoria, South Africa
e-mail: acooper@csir.co.za

K. Sinvula
e-mail: ksinvula@gmail.com

S. Steiniger
CEDEUS & Department of Transportation & Logistics,
Pontifical Catholic University of Chile, Santiago de Chile, Chile
e-mail: ssteiniger@uc.cl

B. Köbben
ITC—University of Twente, Enschede, Netherlands
e-mail: b.j.kobben@utwente.nl

A. Iwaniak · I. Kaczmarek
Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland
e-mail: adam.iwaniak@up.wroc.pl

I. Kaczmarek
e-mail: kaczmarek.iw@gmail.com

P. Rapant
Institute of Geoinformatics, Faculty of Mining and Geology,
VSB—Technical University of Ostrava, Ostrava, Czechia
e-mail: petr.rapant@vsb.cz

M.P. Peterson (ed.), *Advances in Cartography and GIScience*, Lecture Notes in Geoinformation and Cartography, DOI 10.1007/978-3-319-57336-6_8

services between stakeholders from different levels in the spatial data community. Universities and other research organisations typically have well-established libraries and digital catalogues for scientific literature, but catalogues for geospatial data are rare. Geospatial data is widely used in research, but geospatial data produced by researchers is seldom available, accessible and usable, e.g., for purposes of teaching or further research after completion of the project. This chapter describes the experiences of a number of SDI implementations at universities and research institutes. Based on this, the Academic SDI, an SDI for research and education, is defined and its stakeholders are described. The purpose, scope and stakeholders of the Academic SDI are described based on the formal model of an SDI developed by the International Cartographic Association (ICA) Commission on SDIs and Standards (formerly the Commission on Geoinformation Infrastructures and Standards). The results contribute to understanding the state-of-the-art in SDI implementations at universities and research institutes; how the Academic SDI differs from a 'regular' SDI; and which role players need to be involved in a successful SDI implementation for research and education.

Keywords Spatial data infrastructure · SDI · University · Research · Education · Stakeholder

F.-J. Behr
Stuttgart University of Applied Sciences, Stuttgart, Germany
e-mail: franz-josef.behr@hft-stuttgart.de

G. Schoof
GIS Centrum Voor Informatie Technologie, Rijksuniversiteit Groningen, Groningen, Netherlands
e-mail: g.schoof@rug.nl

S. Katumba
Gauteng City-Region Observatory, A Partnership of University of Johannesburg, University of The Witwatersrand (Johannesburg), Gauteng Provincial Government and Organised Local Government in Gauteng, Johannesburg, South Africa
e-mail: samy.katumba@gcro.ac.za

R. Vatseva
National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria
e-mail: rvatseva@bas.bg

H. Moellering
Harold Moellering, Department of Geography, Ohio State University, Columbus, OH, USA
e-mail: moellering.1@osu.edu

1 Introduction

A national spatial data infrastructure (SDI) facilitates the sharing of public geospatial data within a country. Similarly, SDIs maintained by regional and local governments permit data sharing at different administrative levels. The situation is different in the field of education and research. Like books and journals, geospatial data is also widely used in research, but geospatial data produced by researchers is rarely distributed to others or archived properly, and therefore seldomly registered in specialized data catalogues.

Implementations of SDIs and associated catalogues of geospatial data at universities and research institutes would improve the availability, accessibility and (re-)usability of geospatial data by scientists and others (Bernard et al. 2014). This would not only make it possible to use the same data in subsequent research, but—with an eye on publications and research integrity—would also enable reproducible research, and perhaps, most importantly, make research results accessible to funders and to the public.

This chapter presents a brief overview of SDI implementations at research institutes in Chile and South Africa and at universities in Czechia, the Netherlands, Poland and South Africa. The implementations are described in more detail in Coetzee et al. (2017). For each Academic SDI, the purpose, stakeholders and lessons learned are presented based on the formal model of an SDI developed by the International Cartographic Association (ICA) Commission on SDIs and Standards (formerly the Commission on Geoinformation Infrastructures and Standards) (Hjelmager et al. 2008).

2 Demand for SDIs at Universities and Research Institutes

Research in many disciplines requires geospatial data that describe urban, rural or natural landscapes. For instance, geography ranges from cultural geography over physical geography to economic geography and requires a multitude of data, including demographic, economic, urban infrastructure, land cover and land use data (Haggett 2001). As knowledge evolves, newer methods and approaches are developed and influenced by research(ers) from different disciplines, resulting in inter-disciplinary methods and approaches. For instance, for transportation planning nowadays one needs to take geographical, demographical/social, psychological and environmental aspects into account (Sagaris 2014). Academic SDIs can help to fulfill these wider data needs in different ways.

Apart from demand for SDIs in research, there are two distinct roles for SDIs in education. Firstly, as a tool to make data searchable and accessible for exercises, projects and thesis work. This is relevant for students across a broad range of disciplines where geospatial data is used. Secondly, in programmes where geographic information technology itself is the subject of study, the teaching methods are founded in engineering science. Here, the SDI can serve as a best practice example by exposing students to SDI technology as a subject of study, and by creating a realistic working environment.

Implementing an SDI presents the opportunity to make data and research results available internally and externally. Publicly accessible results increase transparency towards the public, who often funds research (indirectly), and also allows other (external) researchers to reproduce experiments with the original data. The frequency of non-reproducible research results has raised critical discussions in the science community (e.g., Rey 2014), led to retractions of published papers and prompted publishers (e.g., Nature 2016) into setting new policies on the availability of data, methods and materials presented in research publications.

Data providers also benefit from the availability of, and access to, core geospatial data (such as, topographical data, administrative boundaries, geology, hydrology) in academic research and teaching. There is the opportunity for feedback on data quality and fitness for use; for developing innovative applications and business opportunities; and for students to become 'real' geospatial data users, who are more likely to use such data again when they enter the labour market (Medycky-Scott et al. 2011).

An example of making geospatial data available for universities is the Virtual Map Forum 2.0 at the Saxon State and University Library (SLUB) (Saxon State and University Library 2016) in Dresden (Germany) which provides a map–based graphical user interface allowing spatial-temporal browsing through a collection of historical maps. University library portals with links for accessing geospatial data include MIT Libraries (2016), Michigan State University Libraries (2016), Stanford University Libraries (2016), and the Harvard Geospatial Library (2016). Another example is the Geographic and Statistical Information Centre (Centre GéoStat) of Laval University's Library hosts a collection of raster and vector datasets useful for many different fields. A powerful semantic search and discovery engine, *Géoindex* + , combines traditional text-based search and spatial filters (Ouellet and Biondo 2012). Dodsworth and Nicholson (2015) describe how Google Earth can be used as a data retrieval tool in libraries. Scanned maps are georeferenced and presented together with digital geospatial data (in KML) on a virtual globe.

Despite the many benefits, most universities do not have an SDI for research and education. For example, at the Stuttgart University of Applied Sciences (Germany), where GIS and geospatial science is taught in several Bachelors and Masters degrees, the geospatial data resources are listed in the university's central e-learning platform without search or download capabilities.

3 The ICA's SDI Model

The ICA Commission on SDI and Standards has developed a conceptual model of an SDI (Hjelmager et al. 2008; Cooper et al. 2011, 2012). The model describes an SDI from different viewpoints specified in the Reference Model for Open

Table 1 SDI stakeholders (*Source* Hjelmager et al. 2008)

Stakeholder	Description
PolicyMaker	Sets the policy pursued by an SDI and all its stakeholders
Producer	Produces SDI data or services
Provider	Provides data or services to users throughout SDI
Broker	Brings users and providers together and assists in the negotiation of contracts between them
Value-added reseller (VAR)	Adds some new feature to an existing product or group of products, and then makes it available as a new product
EndUser	Uses the SDI for its intended purpose

Distributed Processing (RM-ODP) (ISO 1998). Each viewpoint provides a different abstraction of the SDI. The model describes six SDI stakeholders (see Table 1). It has been applied to understand several SDIs, e.g., Sinvula et al. (2017); here we use it to describe stakeholders in an Academic SDI.

4 SDI Implementations at Universities and Research Institutes

4.1 University of Twente, The Netherlands

At ITC (now part of the University Twente), an initiative was started, already in 1999, to set up what was then called a Common Database Project (Hootsmans et al. 1999). Although not yet named an SDI, it was one for all intents and purposes, as can be seen from the setup in Fig. 1.

The purpose was to gather experience in-house with the integrated approach that we nowadays call SDI. A secondary purpose was to demonstrate the benefits of such an SDI in comparison to the (at that time) conventional ways of structuring, storing and distributing geospatial data. Stakeholders are described in Table 2; lessons learned are listed in Table 3.

4.2 University of Groningen, the Netherlands

Geodienst successfully implemented a spatial expertise group with the goal of *'Enabling better research through the use of spatial information'*. Since this has proven to be difficult for many institutions it is an interesting case. The focus is not on the SDI or tools, but rather on the applications of customers. Tasks are to promote the application of spatial information actively; to provide expertise; and to manage data, infrastructure and software.

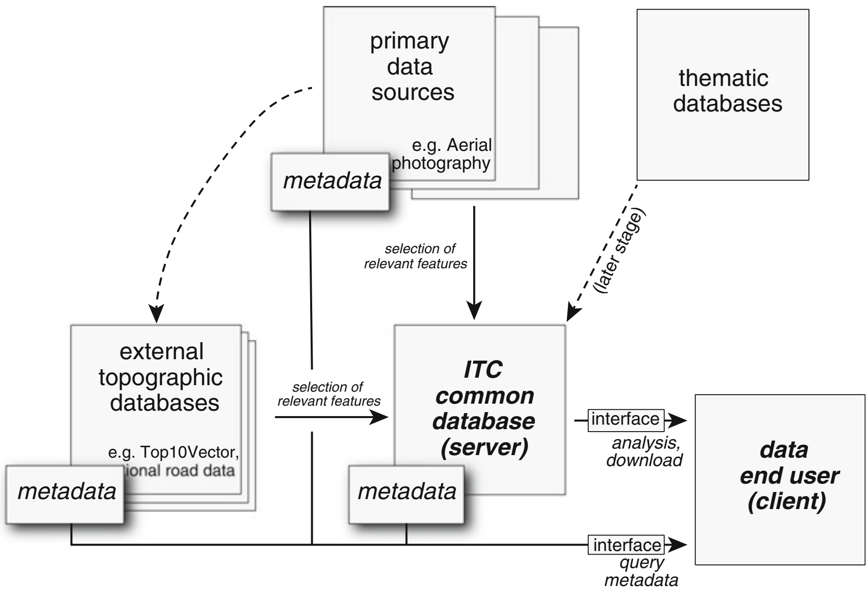

Fig. 1 Setup of the Common Database Project (CDP) (from Hootsmans et al. 1999)

Table 2 SDI stakeholders: University of Twente

PolicyMaker	Four-person steering group
Producer	(National) Mapping and Cadastral agencies ITC staff
Provider	ITC
Broker	n/a
VAR	Students and researchers
EndUser	Students and staff (researchers and educators)

Table 3 Lessons learned: University of Twente

PolicyMakers were mostly interested in the technological side and did not manage to identify, let alone activate, the main stakeholders, especially the EndUsers
SDI technology was still in its infancy and standards did not exist, e.g., the WMS 1.0.0 standard was only published a year later (OGC 2010). Probably, the CDP came a little too early to be successful
CDP as a learning tool was a success because ITC staff gained early and hands-on exposure to the technology and organisational aspects of SDI
CDP has led to the integration of the SDI^{light} concept (Köbben et al. 2010) in all teaching at ITC: the principles of SDI are applied so that the SDI serves as subject of study, as well as a working environment

Table 4 SDI stakeholders: University of Groningen

PolicyMaker	Geodienst management, Faculties, CIT Board
Producer	Data is harvested from different sources Own productions or alterations
Provider	Geodienst
Broker	n/a
VAR	n/a
EndUser	Researchers, teachers, students and administrative staff

Table 5 Lessons learned: University of Groningen

An SDI involves not only the hard- and software but also GIS-expertise and communication
Focusing on the SDI itself does not lead to success; one has to focus on the barriers and remove them, whatever they may be
Promotion is important; one has to take responsibility for selling the idea of an SDI, don't wait for others to do it
Students are capable of handling responsibilities in an SDI implementation
Results, together with political goodwill, lead to permanent funding

Geodienst is organised like a start-up, with very little organizational hierarchy and a lot of freedom and responsibility. This leads to quick and pragmatic responses to support calls and projects, fast internal learning, but a bit of chaos. More information is available at http://rug.nl/geo. Stakeholders are described in Table 4; lessons learned are listed in Table 5.

4.3 VSB—Technical University of Ostrava, Czechia

The Institute of Geoinformatics, VSB—Technical University of Ostrava (VSB-TUO), Czechia, participated in the development and deployment of the meta-information system, MIDAS (MetaInformation Database System) (Paukner-ova et al. 2002), which was established, amongst others, as a pilot meta-information system of public administration.

Many teams at VSB-TUO work intensively with geospatial software and data from both internal (e.g., collected through research) and external (e.g., licensed to the whole VSB-TUO) sources. The Institute addressed other teams with the offer to establish a meta-information system for VSB-TUO based on MIDAS with the aim of becoming the foundation of the university's infrastructure for geospatial data and services.

Unfortunately, the *EndUsers* could not be convinced of the usefulness of this system, and eventually it was decided to terminate the project. Stakeholders are described in Table 6; lessons learned are listed in Table 7.

4.4 CSIR, South Africa

The CSIR, a public science council, operates through a number of largely independent business units. The CSIR contributes in various ways to base geospatial data sets of several South African SDI custodians. A basic SDI makes base geospatial data available internally. Sharing of geospatial data across business units outside of projects is limited, because of commercial sensitivities, protecting personal data, and military and other secrets. Because costs are incurred at the lowest level in the organisation, it is difficult to establish large and expensive organisation-wide systems, such as a comprehensive SDI. Stakeholders are described in Table 8.

4.5 Research Centre for Sustainable Urban Development (CEDEUS), Chile

The CEDEUS research centre unites university researchers that work on different aspects of urban development, e.g., use of natural resources, transport and mobility,

Table 6 SDI stakeholders: VSB—Technical University of Ostrava

PolicyMaker	A group of interested people with no institutional support
Producer	External data producers data collected by EndUsers during research or teaching
Provider	MIDAS (MetaInformation Database System)
Broker	n/a
VAR	n/a
EndUser	Research and educational groups, researchers and students

Table 7 Lessons learned: VSB—Technical University of Ostrava

To ensure wider acceptance, institutional support from the VSB-TUO would be required
No awareness of the importance of data (not only geospatial data) at the university level and consequent absence of university policies in this area
Concerns of faculties, researchers and educators that they would have to fund the SDI
Reluctance to share data
Fear of losing control over datasets when they are stored centrally

Table 8 SDI stakeholders: CSIR

PolicyMaker	CSIR Executive
Producer	Custodians
Provider	CSIR Computing Services
Broker	n/a
VAR	n/a
EndUser	Naive to expert, some source and maintain themselves all their data

Table 9 SDI stakeholders: CEDEUS

PolicyMaker	GIS/SDI team and CEDEUS board of directors (i.e., principal investigators)
Producer	Data producers: GIS/SDI team, researchers, also 'external sources', such as governmental authorities (i.e., ministries) and other research centres or universities Service producer: GIS/SDI team
Provider	GIS/SDI (original intentions were that all (40) CEDEUS researchers and technical staff would be Providers)
Broker	GIS/SDI team, and the data platform of the hosting university
VAR	CEDEUS (sustainability indicators for cities based on SDI data)
EndUser	GIS/SDI team, researchers, and the public: mainly (thesis) students, postdocs, a small portion of centre and external researchers and educators, but most importantly, also the public

Table 10 Lessons learned: CEDEUS

CEDEUS researchers turned out to be fairly resistant to learn and use the SDI. The number of student EndUsers is growing.
Unexpectedly, some documents (i.e., municipal development plans from some municipalities) experience demand from the public, most likely because some municipalities have not made these documents available online
Success of data demand depends on (a) attractive data (i.e., focused on certain users and their demand); and (b) public relation strategies to make the SDI known to others (e.g., social networks, introductory GIS workshops for students, indexing of the SDI content by Google's Search engine)
The SDI has not reached its objective of researchers sharing their data. The country's (research) culture with a strong thinking of 'data ownership = research advantage' plays a strong role

built environment and social segregation. The centre's SDI, called Observatory was funded to support the centre's proclaimed goals—amongst others, to encourage inter-disciplinary research; to monitor urban development; and to propose public policies—in the form of a service unit. That is, the SDI team provides a 'drop box' and catalogue of geospatial data and offers training and support to students and researchers not familiar with GIS. Stakeholders are described in Table 9; lessons learned are listed in Table 10.

4.6 *University of the Witwatersrand (Wits), Johannesburg, South Africa*

The GIS and remote sensing group is a multi-disciplinary group with members across Wits who develop and use GIS and remote sensing for teaching and research.

Table 11 SDI stakeholders: Wits

PolicyMaker	School of geography, archeology and environmental studies (GAES) approves policies GIS and remote sensing group champions the initiative and also plays the role of secretariat for the initiative
Producer	Gauteng city-region observatory (GCRO) and other private and public sector producers
Provider	Data: GAES (on ftp server) Services: members of the GIS and remote sensing group
Broker	n/a
VAR	Data providers may act as VARs
EndUser	Students, academic staff, group members and the general public

Table 12 Lessons learned: Wits

Even though there is much enthusiasm among the members of the GIS and remote sensing group, who continue to increase in numbers, there is currently no buy-in GAES to support the efforts with funding

The fields of expertise include geography, archaeology, environmental studies, geosciences, statistics, computational sciences, engineering, health and social sciences. The group of approximately 20 members (lecturers, researchers and IT professionals) produces various freely available services, tools and datasets for spatio-temporal analysis. Data from external sources and value-added data, obtained as output from research work, are shared through an ftp server. In 2013, the group initiated a project of constructing a spatial geodatabase and also expressed the need for a university-based server that can meet the needs of the wider group of users across campus. Stakeholders are described in Table 11; lessons learned are listed in Table 12.

4.7 Academic Geo Hub Platform, Wroclaw University of Environmental and Life Sciences (Poland)

The main objective of the Academic Geo Hub Platform was to create a common platform for the exchange and sharing of geospatial data for scientists in Poland. It was established in 2015 as a part of the PLGrid NG project ('New generation domain-specific services in the PL-Grid Infrastructure for Polish Science', 2014–2015) carried out by the PL-Grid Consortium.

Today, the Academic Geo Hub is a repository, which acts as a science laboratory combined with a social networking service and semantic web solutions. Users can transfer, download, integrate and publish data, as well as manage access to them. It

Table 13 SDI stakeholders: Wroclaw University of Environmental and Life Sciences

PolicyMaker	PLGrid NG project steering group
Producer	Public administrators Academic community (both researchers and students)
Provider	Wrocław Centre for Networking and Supercomputing, Wrocław University of Technology
Broker	n/a
VAR	n/a
EndUser	Academic community (both researchers and students)

Table 14 Lessons learned: Wroclaw University of Environmental and Life Sciences

Due to limited awareness of open data at the time, only few public entities agreed to share their data for the project. This has changed and it may be good timing to re-establish cooperation with them now
The main difficulty in the functioning of the platform is the lack of a business model and policies for SDIs in education and research. As a result, there is no permanent funding and therefore maintenance of the platform in the long run is difficult

supports collaboration among research teams, especially for young researchers who have obtained partial results, not yet published in journals. Stakeholders are described in Table 13; lessons learned are listed in Table 14.

5 The Academic SDI

Following the descriptions in the previous section, the purpose of the Academic SDI is to make geospatial data produced for and by research and education discoverable, accessible and usable, primarily within universities and research institutes, but sometimes also for a wider audience, such as the general public. An Academic SDI may be implemented for users from a single organisation (i.e., a single university or institute), or for users from multiple organisations (i.e., several universities or institutes).

Figure 2 provides a first impression of Academic SDI stakeholders, based on the ICA's SDI model and the SDI implementations presented in this chapter. Classes with a transparent background are original classes from the ICA's SDI model; classes with a gray background are specialisations for research and education. In future work, these stakeholders need to be elaborated in more detail, e.g., post-doctoral students and technical support staff are not yet represented.

Data provided by an Academic SDI originates from many different sources and does not only include data created within the organisation; data may also be produced (and maintained) by external entities, such as government entities or other Academic SDIs. Ideally, the Academic SDI integrates geospatial datasets from

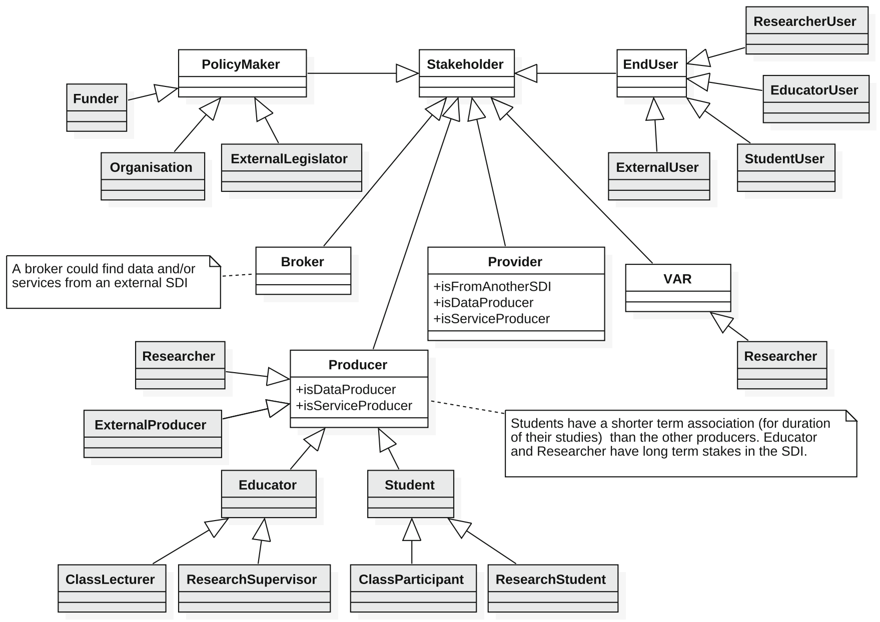

Fig. 2 Stakeholders in the Academic SDI

external SDIs through harvesting metadata. The metadata for datasets produced by researchers has to describe the process or scientific method for developing the dataset.

In many cases, the Academic SDI facilitates access to already existing data produced by other researchers. In these cases, the researcher is considered to be a *VAR*, i.e., the researcher adds value to already published data, though this will not necessarily be for resale.

An Academic SDI is different from a ‘normal’ SDI in various ways. The SDI implementations described in this chapter show that the relationship between the *Producer*, *Provider*, *PolicyMaker*, and *EndUser* is much closer and more collaborative in nature than in an SDI by a public administration with a top-down data distribution model. Therefore, an Academic SDI often resembles a bottom-up or demand-driven approach and *EndUsers* should therefore be represented among the *PolicyMakers*.

Furthermore, the Academic SDI is not built on the basis of legislation (e.g., administered by a Minister of Education), but in response to project and teaching requirements at universities and research institutes. Due to the silo nature common in academic and research institutions and limited sharing of data sets because of project sensitivities, data hoarding, etc., an Academic SDI tends to consist of a federated set of data islands rather than an integrated network of connected data nodes. Also, there is no central access point to data compiled by researchers. Without a (university) policy that imposes data sharing, establishing an

Academic SDI will always be a challenge because each individual has to be convinced to participate in the SDI.

Due to the close relationship between *Producers*, *Providers* and *EndUsers* in an Academic SDI, the SDI very often contributes to education and capacity building. *Producers* and *Providers* (e.g., researchers, educators and postgraduate students) who maintain the SDI improve their own skills and can train *EndUsers* (e.g., other researchers and undergraduate students) on geospatial information and its applications. Considering the educational environment, the Academic SDI serves not only as data source for teaching, but can also be used as a training platform for students who have to learn how to implement and manage an SDI.

6 Discussion and Conclusion

This chapter presented a first description of an SDI for research and education, the Academic SDI. The description draws on SDI implementations at selected universities and research institutes in the Czechia, Chile, the Netherlands, Poland and South Africa. The Academic SDI is described according to the formal model of an SDI developed by the ICA Commission on SDIs and Standards. The purpose, scope, important stakeholders and first lessons learned from SDI implementations at universities and research institutes are identified. This description of the Academic SDI is a specialization of the general SDI model developed by the Commission.

An Academic SDI can serve as a common data exchange platform in the sense of a geospatial data 'drop box', which researchers use to upload, search, and download data (Bernard et al. 2014). Apart from benefits relating to the availability of data from different sources, there are time and cost savings by avoiding duplication of data collection and acquisition across different universities or research institutes (Rajabifard and Williamson 2001; Crompvoets et al. 2004). With an Academic SDI comes furthermore the opportunity for creating a team of experts who manage and maintain the Academic SDI, train people from different fields in the use of GIS, develop and promote best (mapping) practices and generally raise awareness of the value of geographic information.

A significant barrier to SDI implementations described in this chapter was the absence of sustainable multi-year funding with respect to equipment and personnel. A second significant barrier was the lack of awareness among decision makers in the organisation and/or funding agencies of the value of the information itself, and of sharing information. Consequently, policies to manage data produced by research within the institutions are lacking.

The value of an SDI can be measured in two ways: firstly, by outlining the utility of geospatial information for research and education, and secondly, by estimating the time and money saved through sharing. For an Academic SDI, the value of the SDI as a training platform can be added. Similar to 'regular' SDIs, one has to be aware that the cost-benefit of an SDI is difficult to determine and benefits take years to realize, amongst others, due to resistance or reluctance by researchers to accept such 'new' technology; the reluctance to share data because of the fear to lose control over a publication or further research advantage; and lacking awareness of the SDI among potential users outside the organisation.

The information about stakeholders and their roles, problems and success factors with SDI implementations contributes to the elaboration of the state-of-the-art in the implementation of Academic SDIs. It gives first hints on the stakeholders needed and how they may be involved in an SDI implementation at a university or research institute. Future work should describe the Academic SDI in more detail, e.g., how to implement it.

Acknowledgements Stefan Steiniger is grateful for funding by Conicyt (Conicyt/Fondap/15110020 and Conicyt/Fondecyt/1150239). Samy Katumba acknowledges the assistance and cooperation of Dr. Stefania Merlo, Chair of the GIS and remote sensing group at the University of the Witwatersrand, South Africa.

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