Spatial Data Infrastructures

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Spatial data infrastructure (SDI) for sustainable land management

Richard Groot

ABSTRACT

This paper elaborates on perspectives presented in the recent literature, which identify increased use of geoinformatics in the design of interdisciplinary geo-information systems and decision support systems for realizing sustainable land management at different scales and for specific user groups. The realization of the potential of geo-information systems in supporting sustainable land management depends on a number of factors. Efficient and reliable access to well-harmonized information is one of these. In this respect, the literature also alludes to an emerging digital geo-information infrastructure and policy framework at global, regional, national and local levels, which will make available, for example, significant soil research output that is now inaccessibly stored in archives and libraries. The paper presents the concept of geo-information infrastructure (GII) or spatial data infrastructure (SDI) as a tool to facilitate access to, and responsible use of geo-information at affordable cost in support of sustainable land management. It presents the notion that a national SDI is composed of networked SDIs which have been designed and implemented to serve very specific application sectors at the national, regional or municipal level. “Sustainable land management” could be such an application sector. The paper traces the history of the development of the SDI concept. It identifies the high expectations of national information infrastructure (of which SDI is a subset), in terms of achieving new economic and social development goals and improved public services, since President Clinton introduced the “electronic information highway” metaphor in his political platform. These expectations have also been expressed in the “information society” initiatives of the European Union. The paper illuminates the necessity of the legal and regulatory changes which will have to be made in order to achieve the open geo-information market that must be at the foundation of the expectations expressed. It will make the case that the technical developments and the institutional, organizational and human resources development in the design, implementation and maintenance of SDIs for a specific application sector must run in parallel. Successful sustained implementation will depend on clear “political” accountability for its integrity, and on a local regulatory environment that is in harmony with the more senior legislation and regulation at, e.g., the national or supranational levels. The paper concludes with a set of recommended practices in the development of SDI.

To someone outside the field of sustainable land management, performing a rather cursory scan of recent literature, it is comforting to note that the thinking about land management and its professional practice has been at least as demanding as in my own field of surveying and mapping. In the latter, the combination of computer and communication technologies has been the driving force behind the manner in which the tasks of my profession are now perceived. Recognizing the profound changes in the profession, we no longer call it surveying and mapping but geomatics or geoinformatics. Furthermore, these technologic changes have provoked many national surveys to a critical consideration of their historic mandates, their standard activities and products, and their relationships with their clients, the private sector and other levels of government.

It appears that the land management profession has been affected considerably by the concept of sustainable land management (SLM). The evolution of land use planning to land management to sustainable land management shows that new names are reflecting new perspectives. In the operationalization of the SLM concept, the required interdisciplinary approaches demand the integration of many disparate datasets of varying pedigree. Furthermore, a great deal of innovation in the modelling of social and economic phenomena, physical phenomena and their interaction has been associated with this concept. In the management of the datasets, as well as the application of these models, we look to information technology for solutions. Hence, information technology is playing a more critical and complex role than necessary, for example, in the automated drawing of soil maps or other maps.

As these developments are unfolding, it is also becoming evident that efficient access to appropriately structured and spatially referenced data from many different sources is a necessary condition for realizing the full potential of information technology applications. To satisfy this condition, the concept of spatial data infrastructure (SDI) has been developed. The traditional tasks of national survey institutes may have to be considered in this light to ensure their ongoing relevance.

In this paper, I would like to elaborate on the “perspectives” presented by Beek [3]:

“(1) Information Technology will increasingly facilitate the development of integrated quantitative studies of land use systems based on the simulation of dynamic land use interactive processes.

(2) There is a strong tendency towards increased use of geo informatics in the design of interdisciplinary geo information systems and decision support systems for realizing sustainable land management at different scales and for specific user groups. A digital geo information infrastructure and policy framework is emerging for this purpose at global, regional, national, and local levels. This will make a significant soil research output available that is now inaccessibly stored in archives and libraries” [2].

The elaboration will concentrate on the part in italics. The concept of spatial data infrastructure (SDI) will be introduced. Although one could perceive of SDI at the global, regional, national or local level, both in government and the private sector they all have a similar structure which also supports their connectivity. This structure will be explained. The design, implementation and maintenance of SDI is not, however, a purely technical challenge.

SDI operates subject to policies that govern access,
use, pricing of services, sustained financing, quality management and human resources development.

These local policies must operate within national or regional information policy constraints. The field of information policy is evolving from analogue applications (printed products and telecommunications) to digital, and is thus subject to change at this point in time. This, in turn, could in some cases create uncertainty for the elaboration of consistent policies concerning the access, use and financing of a particular SDI application.

This paper explains the conflicting policies many national surveys (including soil surveys) have to cope with in specifying their niche in the national spatial data infrastructure (NSDI). It concludes by suggesting some recommended practices in the design, implementation and maintenance of, for example, an SDI supporting sustainable land management.

**SPATIAL DATA INFRASTRUCTURE (SDI) TERMINOLOGY**

The term “spatial data infrastructure” (SDI) is interchangeably used with the terms “geo-information infrastructure” (GII) and “geospatial information infrastructure” (also GII). SDI seems to be the term preferred in the USA literature. In Europe, particularly in Britain, the term “geospatial” is often used. Although I prefer the term “geo-information infrastructure”, its abbreviation can be confused with that of the emerging but generally accepted term “global information infrastructure” (GII). The term “geospatial information” is something of a pleonasm and therefore not preferred. Hence, in this paper, I have used the term “spatial data infrastructure” (SDI).

**HISTORY**

Since the late 1970s, many national survey and mapping organizations have begun to recognize the need to justify the large public investments they received by improving access, and encouraging a broader use of the information in their custody. They developed strategies and processes to standardize access to this information and its applications. During this process, they were forced to reconsider their traditional tasks. In most cases, they had to redefine their standard production lines, and develop new ones to respond to the demand for specialized products from a growing community of users demanding rapid access to digital framework data. In the 1980s and early 1990s, many countries (e.g., Canada [7], the United Kingdom [8], the United States [15], the Netherlands [17]) undertook extensive reviews and studies to demonstrate the cost-effectiveness of their national survey activities, and particularly to demonstrate how this could be improved using information technology (IT).

In Canada, the area of concentration where the term “geo-information infrastructure” emerged concerned the harmonization of the topographic activities between federal and provincial agencies. Their purpose was to facilitate the exchange of surveyed and mapped information in their respective domains, thereby eliminating duplication and improving the topicality of the maps and associated databases. At first, the standardization was perceived, and also implemented, as a purely technical process: the standardization of the data definitions, the coding and the exchange formats. Over time, however, it became clear that the parties needed to agree on common policies with respect to the access, use and pricing of their data. Without such common policies, it would be easy for users to select the cheapest supplier and thus deprive the data owners of clientele and, more importantly, of revenue to support the budgets of the survey organizations. Furthermore, the two levels of government had to agree on the terms for users exploiting their respective data and how they would charge for this. Hence, it became increasingly apparent that, in terms of achieving the expected improvements in effectiveness and efficiency, the technical standardization had to be accompanied by standardization or at least harmonization at the institutional levels. This proved far more complex than expected.

**INFORMATION INFRASTRUCTURE AND ECONOMIC DEVELOPMENT**

The term “infrastructure” was first used in the middle of the 18th century in relation to railway tracks and rights of way for trains. Its meaning has evolved to include a complex of shared structures and services that support broad social participation and economic activity. In this sense, we all recognize roads, electric power, energy transmission, telephone services and networks, etc., as infrastructure. An important characteristic is that “they have significant economies of scale and spillover effects on non-users, particularly as enablers of other forms of economic activity” [18].

When the Clinton administration took office in 1992, the “information superhighway” initiative was announced: “the national information infrastructure (NII)”. It was the centerpiece of a well-orchestrated set of government strategies, including a variety of social, economic and technology policy areas. The superhighway metaphor had immediate intuitive appeal as it created a link with the 1950s, when the government initiative in creating a network of interstate highways was an important component of stimulating economic development. Furthermore, the emerging Internet could be used as an example to explain the metaphor.

The essence of the NII focus was that it “argued for a dramatic shift in US telecommunications policy away from a previously limited role for government as a regulator. Instead, the government’s involvement was seen to be a broader one of promoting the development of new Information and Communication Technology (ICT) structures, services, and products in order to help address major social and economic objectives, such as improving public services, democratic processes, and national competitiveness.” ([11], italics by the author).

Although the information superhighway metaphor served to put the NII clearly on the political agenda, the term was seen by some people as being too oriented towards the hardware and not enough towards the societal, social and economic elements of the NII. For example, Talero [18] states that “… there are several information systems that have such strategic importance to the economy that they can be considered infrastructure.” One of the eight types he mentioned was “to facilitate general economic activity: national statistics, geographic information, ….” His definition of NII is: “the telecommunications networks and strategic information systems necessary for sustainable economic development.”
In 1989, the Commission of the European Communities (CEC) issued its guidelines for improving the synergy between the public and private sectors in the information market. These guidelines, which are only advisory, “were considered essential to help the public sector in decision making related to making information available for external use and supporting the development of the information market; and to establish ground rules for avoiding possible unfair competition” [9].

It was a clear message that, at the highest levels in the European Community, the economic importance of free access to databases created by public funds and the role of the private sector in adding value to the information production were recognized. The European Union followed in a similar vein with the Bangemann Report, a wide-ranging set of recommendations as to how the EU would provide leadership to its member countries for their entry into the information society [1]. Although not exploiting the superhighway metaphor, the EC, like the Americans, focused on social and economic objectives in, eg, healthcare delivery, continuing education and the “information market place”. In other words, the EC emphasized the emerging information society.

Within the context of these initiatives, the European geographic information infrastructure had to be addressed. In 1994, work started on a working document Towards a European Policy Framework for Geographic Information, in the context of the Info 2000 programme, under DG XIII (the Directorate General responsible for information technology in the EU). In this document, the overtone is that of the commercialization of government-owned geo-information to stimulate economic development and support a variety of policy initiatives. In 1995 and 1996, the European workshops “Geodata for All” were held as the first two of a planned ongoing series. A first description of the concept was presented by Brand [4]. The coordination of institutional activities has since been carried out by the European Umbrella Organization for Geographic Information (Eurogi), which was created in 1993.

The significance of these initiatives at the national and supranational levels is that the design and implementation of local SDI can no longer be performed only from the bottom up, so to speak, between survey and mapping organizations at different levels of government as in the Canadian example. Now the technology, standards and the policy framework governing the local application, especially if it is government-owned, must be harmonized with the higher-level policy framework. Thus, issues concerning the protection of intellectual property and privacy, the electronic and legal protection of data, and competition policy will affect the design, implementation and exploitation and/or financing of a local SDI.

Hence, local developments must take into account what has come to be known as national, and increasingly international, information policy. It has been defined by information scientist Peter Hernon as “a set of laws, regulations, directives, statements, and judicial interpretations that direct and manage the life cycle of information. That life cycle encompasses planning, and the creation, production, collection, distribution and dissemination, and retrieval of information” [14]. As technologies converge, it is expected that previously distinct and separate policy areas related to information will also converge [6]. For a concise explanation of the dimensions of the policy debates, see Dutton [11].

The literature suggests that the proposals for an information infrastructure illustrate the departure from the national outlook to an international approach, driven primarily by a market-oriented attitude and the interests of transnational corporations as opposed to public interest ideology [5].

In conclusion, SDI supporting SLM will contain what Talero has termed “strategic datasets”, which should be defined and implemented with a view to making them available to a broader audience than simply land managers. Thus the SDIs for SLM cannot be implemented from only the scientists’ perspective on sustainable land management.

Against this background, the question of course is how can we implement local SDI in such a complicated environment that is also extremely dynamic and subject to local (and national) interpretation? The rest of this paper aims to explain the basic components of the SDI structure and to recommend some guidelines for its design, implementation and sustained operation.

THE PURPOSE AND COMMON STRUCTURE OF SDI

The Purpose

The purpose of SDI is:

- to save time, effort and money in accessing spatial data and using it responsibly
- to avoid unnecessary duplication in the harmonization and standardization of required datasets by promoting the sharing of available data.

Of course, the fact that government departments or different levels of government can share data effectively does not guarantee that better public services are being provided to the citizens. It is therefore important at the start of an SDI implementation to clarify who will be the ultimate beneficiaries at citizen level. For example, will environmental issues be addressed more effectively or building permits issued faster and more objectively? Unless the implementation of SDI results in this type of progress it is not worthwhile. Or will SDI facilitate access to, and the responsible use of spatial data at affordable prices?

“Facilitate access” means letting the user know what information is available and where, what the conditions of access and use are, and how much it will cost. The reference to “responsible use” implies an obligation on the part of the data suppliers to include qualitative information about the data which lets the user determine how fit the data are for use in his/her application. The reference “affordable price” signifies that a degree of price differentiation is possible depending on what the user is prepared to pay for the information or the associated information service. The economic characteristics of government-owned geo-information as an “imperfect public good” strongly influence this process [10].

It is interesting to note that one of the first geo-information infrastructures in operation was not a government but a private sector one. In 1990, a number of oil and gas companies in western Canada had determined that their exploration geologists and geophysicists spent more than 60 percent of their time searching for information and only about 20 of their time doing something useful with it. They decided to create a shared facility, called the Canadian Oil and Gas GIS (Canoggis), in
Spatial data infrastructure

The Common Structure of SDI

National spatial data infrastructure (NSDI) can be thought of as a set of networked SDIs, each set up to serve a certain sector of applications, in terms of the objectives stated above. These sectors of application lie in the fields of, e.g., environment and physical planning, agriculture, transportation, etc. Furthermore, a particular application sector may require data from the municipal, provincial or national level and data connectivity and harmonization between those levels. This implies a requirement for data at a different resolution or scale. This, in turn, has consequences for the relationship of the data definitions and semantics from the larger-scale level to the smaller-scale level. It should not always be assumed that it is possible to derive the smaller-scale level from the larger-scale level by automated means. It is expected that in many cases this will remain, for the foreseeable future, a bottleneck that can only be alleviated by human intervention.

Spatial integration of the data is based on consistent geometric referencing systems and on reasonable compatibility in the resolution of the different datasets. This means that the same coordinate system must be used for the spatial referencing, while excessive variations in the resolution of the datasets must be avoided if meaningful analytical applications are to be achieved. The semantic aspects of the data definition depend greatly on the application context. It is therefore almost impossible to rely entirely on data produced for other purposes. The same geographic feature may be called something different in different application sectors or even in different applications within a particular application sector. Hence, in addition to data that can be shared with others, there will always be datasets which are so application-specific that they are, in the first instance, single-purpose (see Figure 1). (Note, however, that the Canoggis experience indicates that use can expand unpredictably with previously unforeseen applications.)

Figure 1 will be discussed in three parts:

1. The datasets according to a rough classification of foundation, framework and application-specific datasets
2. The set of policies which govern the SDI
3. A description of the main tasks within the “spatial information center” that controls the operation and maintenance of the SDI.

1. Foundation, framework and application-specific datasets

The Mapping Science Committee of the US National Research Council argued for the classification of datasets by foundation and framework [16]; the author has added application-specific datasets. An attempt was also made to define core data needs for environmental assessment and sustainable development strategies [12].

Figure 1 recognizes foundation datasets such as geodetic data (which determine the spatial reference system), fundamental topography (used by many applications as an additional geometric reference represented in the terrain), the digital elevation model, administrative boundaries and postal codes (essential to link socio-economic data to physical data), and official geographic names (still the most used reference for many applica-

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<th>FRAMEWORK DATA</th>
<th>APPLICATION-SPECIFIC DATA</th>
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<td>POLICY IMPLEMENTATION</td>
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<td>METADATA BASE</td>
<td>INFORMATION POLICY DIRECTION</td>
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<td>REAL ESTATE MANAGEMENT</td>
<td>PHYSICAL PLANNING</td>
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<td>ENVIRONMENT PROTECTION</td>
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**FIGURE 1** Structure of the spatial data infrastructure (SDI)
tions). Sometimes digital orthophotos are part of the foundation data, but these require skilled interpreters—not frequently encountered among the users.

It should be recognized that the fundamental topography is not necessarily a digital copy of the topographic maps. For example, in the Netherlands the national topographic survey produces a topo database in vector form at scale 1:10,000 (TOP 10 Vector). This contains approximately the density and attribute values of the 1:25,000 topographic maps—far too much information for most users. There is now a major debate with the user community to define the content and density of attribute values for a suitable and affordable core topographic dataset, although it will be based on the TOP 10 Vector product.

With the possible exception of the administrative boundaries, it will be recognized that the foundation data are produced by the national geodetic/topographic survey organization. Administrative boundaries are often produced and maintained by the national statistical organizations, ie, those responsible for the national census and a variety of social and economic surveys.

Figure 1 also recognizes framework datasets. These are datasets which usually provide thematic information in a national context. This information (eg, on vegetation, land use, land cover and hydrology) may be surveyed directly in the field or by means of remote sensing. Or it may be derived information, such as land suitability for particular purposes. Population distribution and population density by geographic area are also important framework datasets. At any rate, framework datasets provide the thematic geographic framework of the country. The data are produced, maintained, published, distributed and safeguarded by national survey organizations, such as the national soil survey institutes, geologic surveys, hydrologic and climatologic organizations, etc. Although in most countries these organizations are subject to severe budgetary pressures and questioning of their ongoing mission, it is clear that they make a very significant contribution to a country’s historical record, and that they supply and maintain reliable “strategic information” on which sustainable economic development depends.

The application-specific dataset is the last class indicated in Figure 1. These contain information surveyed specifically for a particular application, such as pollution measurements, water chemistry, smog indices, etc. Although these may be useful in a national context to show, for example, the occurrence of smog across a country, they are mostly relevant to only a particular application area.

When we think back to one of the objectives of SDI, the reduction in duplication of harmonizing and standardizing data for applications, we can conclude that:

1. Data-sharing opportunities are very high for foundation data, decrease somewhat for framework data and are even less for application-specific data.
2. National survey organizations must be encouraged and given high priority to defining the foundation and framework data with the user community, and to ensuring that these are produced and maintained to appropriate SDI standards.
3. The policy framework

Access to and responsible use of the above data files at an affordable price is administered through a spatial data (SD) center (see Figure 1). This is done according to a set of transparent policies which ensure that all users know and understand the conditions for access to and use of the data, how much it costs, how their own data will be protected through the SD center, etc. This section of the paper deals with the associated policies.

One can differentiate between imposed legislation and information policy at the national government level or from the more senior administration of which the SD center is a part, and the set of related or complementary policies appropriate to the local SD center (see Table 1 for examples of “senior” policy and “local” policy).

The legislation may, in many cases, be in conflict. For example, a balance needs to be found between free access to government data and the need to protect state information concerning the protection of the realm, the safety of citizens, relationship to other governments, etc. Furthermore, the legislation governing the privacy of the individual and corporations may conflict with that dealing with the commercialization of government information.

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<th>Legislation and senior policy</th>
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<td>Freedom of access to government information</td>
<td>Access and use</td>
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<td>Data protection</td>
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<td>Privacy</td>
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<td>Copyright and intellectual property</td>
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<td>Commercialization of government information</td>
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Currently, many national survey organizations are expected to generate revenue in order to reduce the financial burden of survey activities on the taxpayer. But if this means increasing the prices of data files, or becoming involved in value added information production, there may be conflicts with the legislation governing free access, commercialization, and/or competition.

One can conclude that for the development of the regulations and policies of SDI at the national, provincial or municipal level, the more senior level of legislation needs to be kept in mind. The need for clear regulation and policy at these levels stems from the fact that producers and users of data must know the conditions for access to, use of and prices of the data. The transparency and predictability of these rules is essential for the integrity and smooth operation of the spatial data infrastructure, and the success of the geo-information market place.

3. The spatial data center for sustainable land management

The availability of the foundation, framework and application-specific datasets is not enough to ensure access to and responsible use of the data at affordable costs. An organization is required to carry out some very specific tasks which require specialized expertise not normally available in, eg, national survey organizations. These tasks are indicated in Figure 1 under what has been termed the spatial data center for the sustainable land management (SLM) application sector.
tasks are as follows (this is not a definitive list and may be enlarged with experience).

- Development and maintenance of data standards, data quality management and other performance standards for the SDI:

  This is a field for which expertise needs to be resident in the center. First, it will be necessary to define the data standards in the application sector with the application specialists. This is a tedious and time-consuming task. They need to decide how the application sector classifies (or names) the geographic features of its interest, while taking into account the evolving standards in the field at, eg, the (global) level of the International Standards Organization (ISO) or the level of the Comité Européen de Normalisation (CEN), or standards that may already exist at the national level. The data standardization process is akin to the elaborate conventional process of agreeing on the legend of, eg, a regional vegetation map based on national classification systems, in sympathy with legends agreed upon by international societies. However, in the digital information era the standardization processes are more complicated because of the demands for data sharing by electronic means imposed by the expectations of the information market place and, for example, the European Community’s commitment to it [1].

  The term “evolving standards” is being emphasized here because in the geoinformatics area, as in other fields related to information technology, this is a fact of life. At the same time that we are implementing SDI in a number of countries and organizations, the related standards are still undergoing technical development and are in a consensus-forming process. Furthermore, the standards are dynamic and will continue to evolve in response to the realities of practice.

  The second example stems from the necessity to assure the integrity of the sustained functioning of the SDI. This requires standards for the quality management of the data production in each of the organizations supplying data. Hence, there must be expertise in spatial data production processes to advise data suppliers on how to deal with quality management in their organization. As a minimum, the resident expertise should be able to judge the processes in order to pass judgement as to whether the quality assurance is of a sufficient level to support the integrity of the SDI. An important issue here is that standard methods need to be well defined to identify clearly the “fitness for use” of the various datasets.

  - The financial and administrative integrity of the SDI:

    The SDI and the local SD center need to be financed in some manner. It is unlikely that governments will entertain the idea of providing funds beyond their responsibility for creating and updating the fundamental, framework and application data. All other expenses should be borne by the users of the infrastructure. In this respect, the SDI is no different from the road infrastructure, for which a user fee system has been designed taking account of the user’s fixed costs (vehicle type and license fee) and variable costs (tax on petrol).

    In some cases, governments may decide that the costs for updating the databases must also be borne by the users. But this may fly in the face of universality of access as it may make the data too expensive for the financially weaker members of society, such as a start-up value added information production company.

    The center must be administered in a professional way. Contracts between data suppliers and users must be developed and entered into the system regulating access and use. Billing for data and services must be carried out in a timely and reliable fashion. Associated revenues to data suppliers must be transferred on time and reliably. Hence, the center must have professional expertise in these areas as well.

    The conclusion is that setting up an SD center within an SDI requires new kinds of expertise which must be available in order to ensure the financial and administrative integrity of the operation. Finally, the SD center will be responsible for developing the catalogue of meta data necessary to facilitate the process of identifying what data are available through the SDI and under what conditions they may be used. It will also provide the data and possibly provide services to combine datasets or perform reference transformations, etc—all of course for a fee.

    Hence, an SD center is an organization with very specific tasks and the capacity to fulfill those tasks. In some cases, a question arises as to the regulatory or ownership status of such a center: should it be government owned and operated, government owned and privately operated, or privately owned and operated? Next, what kind of ownership should be It could, for example, be a partnership, or an incorporated company, or a special agency directed by government at arms length. Each of these constructions has advantages and disadvantages, and they should all be considered in the light of local culture and circumstances, when choosing the most appropriate.

CONCLUSIONS

The design, implementation and maintenance of SDI is multi-dimensional and complex. It has technical, organizational and institutional implications that affect the way in which the traditional government data collection organizations perceive their mission, how they relate to users, how they are financed, etc. Organizations responsible for environmental or land management programmes will also find that, with the introduction of information technology, their working methods and organizations will be affected. The conventional information flow through organizations may no longer be adequate, and may therefore require changes. Consequently, the associated (social) structure of the organizations can be expected to change as well [13].

It is imperative that the design and implementation of SDI be carried out in a well managed way, ie, focused on the end user. Otherwise the complexity will tend to drive the development into an academic or impractical direction, whereby organizations will be able to exchange data efficiently but without any impact on the end user, ie, the tax-paying public. This essential focus will also help in managing the apparent complexity.

The data and technical components, the policy and institutional components, and the SD center component demand specific expertise and knowledge about what happens in the related, surrounding and adjacent institutional environments. This suggests that there is a significant component of human resources development in SDI development, which needs to be dealt with prior to, or at least in parallel with the SDI development.
Few SDIs exist as operating entities as yet. A number of government development initiatives are underway in several countries, but success stories are mainly from the private sector, such as the oil and gas industries. It will be difficult to implement SDI in governments because of the shifts in bureaucratic power that will be associated with it. Hence we do not have much experience to fall back on. In almost all cases, the development process must therefore be managed in a careful, businesslike way, with achievable goals meaningful to the end user.

Therefore, we should expect that:
1. The goals and realization of SDI will gradually be achieved in spite of the hype.
2. This will require technical, organizational and institutional changes, which will take time.
3. The implementation must take place in a businesslike fashion, while recognizing that it will be a carefully managed learning process.
4. Flexibility, adaptability and common sense (to distinguish between the “flavour of the month” and significant developments) will be required to deal with the flux in the policy environment, ongoing technological innovation and, in particular, end-user input.

These conclusions lead to a set of recommended practices.

**RECOMMENDED PRACTICES FOR THE DEVELOPMENT OF SDI**

1. SDI development needs a champion at the highest political level. This individual needs to be known to all stakeholders in the project.
2. The beneficiaries of the SDI must be well defined and actively involved in its development and implementation. From the beginning, all the stakeholders must be involved, i.e., data owners and suppliers, users, SD center and financiers, as well as the beneficiaries in the whole development process.
3. The competence of the development team in all aspects mentioned in this paper needs to be developed rapidly and be beyond question among the stakeholders.
4. The development must be broken up into “success blocks”, each requiring low financial commitments and time lines of no more than six months, but with an end product able to generate among the stakeholders and end users a growing confidence in its usefulness.
5. SDI development has few precedents and must therefore be managed as an innovation/technology transfer process.
6. The “success blocks” should be the building blocks in the development of the SDI.
7. The product should not be over-sold until it can be shown to work routinely.

**REFERENCES**


**RESUME**

Cet article est établi sur les perspectives présentées dans la littérature récente, qui identifient une utilisation croissante de géonformatique dans le développement de systèmes d’information géographique interdisciplinaires et de systèmes d’aide à la décision pour réaliser une gestion durable des terres à différentes échelles et pour des groupes spécifiques d’utilisateurs. La réalisation du potentiel de systèmes d’information géographique pour soutenir une gestion durable des terres dépend d’un certain nombre de facteurs. L’un d’eux est l’accès efficace et fiable à une information bien organisée. Dans ce cadre, la littérature fait allusion à une infrastructure d’information géographique naissante et à un cadre politique aux niveaux global, régional, national et local qui pourra permettre, par exemple, rendre disponible, une partie importante des travaux de recherche sur les sols, stockés de manière inaccessible dans les archives et les bibliothèques. L’article présente le concept de l’infrastructure de l’information géographique (IGI) ou l’infrastructure de données spatiales (SDI) comme un outil permettant l’accès et l’utilisation responsable d’information géographique à un coût raisonnable pour une gestion durable des terres. Cet article présente aussi, la notion qu’une infrastructure nationale (SDI) est composée de réseaux SDI qui ont été développés et implantés pour servir des secteurs d’application spécifiques au niveau national, régional et municipal. Une “gestion durable de terre” pourrait être un tel secteur d’application. L’article retrace l’histoire du développement du concept de SDI. Il identifie les hautes attentes d’une infrastructure d’information nationale (dont SDI est une composante) en termes de réalisation d’objectifs nouveaux de développement économique et social et une amélioration des services publics, puisque le Président Clinton a introduit la métaphore “d’autoroute de l’information électronique” dans sa plateforme politique. Ces attentes ont également été exprimées dans la “société d’information”, initiative de l’Union éuro-
**RESUMEN**

Este artículo analiza perspectivas presentadas en literatura reciente, donde se identifica un uso creciente de la geo-informática en el diseño de sistemas interdisciplinarios de información geográfica y de sistemas de soporte a la decisión para el manejo sostenible de las tierras a diferentes escalas y para grupos específicos de usuarios. La realización del potencial de los sistemas de información geográfica en apoyar el manejo sostenible de las tierras depende de un número de factores. Uno de estos factores es el acceso eficiente y confiable a información bien armonizada. En este sentido, la literatura se refiere a una emergente infraestructura de información geográfica digital y un marco de políticas al nivel global, regional, nacional y local, que permitirán el acceso, por ejemplo, a resultados de investigación de suelos, que hoy en día están almacenados en archivos y bibliotecas. Este artículo presenta el concepto de la infraestructura de información geográfica (GII) o de la infraestructura de datos espaciales (SDI) como una herramienta para facilitar el acceso y el uso responsable de la información geográfica a un costo abordable en soporte al manejo sostenible de las tierras. Presenta la noción que una SDI nacional está compuesta de varias SDI interconectadas, que han sido diseñadas e implementadas para servir sectores de aplicación muy específicos al nivel nacional, regional o municipal. “El manejo sostenible de las tierras” podría ser un tal sector de aplicación. El artículo traza la historia del desarrollo del concepto de SDI. Identifica las grandes expectativas de la infraestructura de información nacional (de la cual la SDI es una parte) en términos de alcanzar nuevas metas de desarrollo económico y social y de servicios públicos mejorados, desde que el Presidente Clinton introdujo la metáfora de la “autopista de información electrónica” en su plataforma política. Estas expectativas están también expresadas en las iniciativas de la “sociedad de información” de la Unión Europea. El artículo realiza la necesidad de los cambios legales y regulatorios que deberán hacerse a fin de llevar a cabo el mercado abierto de información geográfica, que debe formar la base de las expectativas expresadas. Esto demostrará que los desarrollos técnicos, institucionales, organizacionales y de recursos humanos deben ir en paralelo en el diseño, la implementación y el mantenimiento de las SDI para un sector de aplicación específico. Una implementación prolongada exitosa depende de una clara responsabilidad “política” para su integridad, y de un ambiente regulatorio local que esté en armonía con la legislación y regulación más antiguas, por ejemplo, al nivel nacional y supranacional. El artículo concluye con una serie de prácticas recomendadas para el desarrollo de la SDI.
Spatial data infrastructures as complex adaptive systems

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Many researchers throughout the world have been struggling to better understand and describe spatial data infrastructures (SDIs). Our knowledge of the real forces and mechanisms behind SDIs is still very limited. The reason for this difficulty might lie in the complex, dynamic and multifaceted nature of SDIs. To evaluate the functioning and effects of SDIs we must have a proper theory and understanding of their nature. This article describes a new approach to understanding SDIs by looking at them through the lens of complex adaptive systems (CASs). CASs are frequently described by the following features and behaviours: complexity, components, self-organization, openness, unpredictability, nonlinearity and adaptability, scale-independence, existence of feedback loop mechanism and sensitivity to initial conditions. In this article both CAS and SDI features are presented, examined and compared using three National SDI case studies from the Netherlands, Australia and Poland. These three National SDIs were carefully analysed to identify CAS features and behaviours. In addition, an Internet survey of SDI experts was carried out to gauge the degree to which they consider SDIs and CASs to be similar. This explorative study provides evidence that to a certain extent SDIs can be viewed as CASs because they have many features in common and behave in a similar way. Studying SDIs as CASs has significant implications for our understanding of SDIs. It will help us to identify and better understand the key factors and conditions for SDI functioning. Assuming that SDIs behave much like CASs, this also has implications for their assessment: assessment techniques typical for linear and predictable systems may not be valid for complex and adaptive systems. This implies that future studies on the development of an SDI assessment framework must consider the complex and adaptive nature of SDIs.

Keywords: spatial data infrastructures; complex adaptive systems; SDI assessment

1. Introduction

Over the last two decades many countries throughout the world have taken steps to establish national spatial data infrastructures (SDIs). These actions have sought to provide an infrastructure for accessing and sharing spatial data to reduce the duplication of spatial data collection by both users and producers, and enable better utilization of spatial data and associated services. However, the great variety and large number of stakeholders, their different needs and the complex relations between them make the implementation of SDIs a very complex business. Moreover, the adoption of innovative technologies makes SDI development very dynamic and leads to differences in the architecture of these infrastructures between countries.

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Many researchers have tried to apply various theories to describe and better understand the complex and dynamic nature of SDIs. The diffusion of innovation theory has been used by many researchers (Chan 2001), such as Onsrud and Pinto (1991), Masser (2005), Masser and Onsrud (1993), Campbell (1996), Masser and Campbell (1996) and Chan (1998), to illustrate and understand the development and adoption of GIS and SDI initiatives within societies. Rajabifard et al. (2000) used hierarchical spatial reasoning (Car 1997) to describe the complex hierarchical structure of SDIs. De Man (2006) applied the concept of institutionalization to explain the linkage between SDIs and spatial data communities and determine how they can be made effective and sustainable. Chan (2001) claims that the perceptions and descriptions of SDIs fail to convey their dynamics and complexity and that therefore a theory is still needed to better understand, describe and evaluate the complex nature of SDIs. Many researchers have indicated that SDI complexity is the main obstacle to its understanding and assessment (Grus et al. 2006). Only when the mechanisms behind SDIs are well explored and understood will it be possible to better develop, manage and evaluate them.

Complex adaptive systems (CASs) theory has been used in many disciplines (e.g. economics, social sciences, organizational studies and biology) to describe and better understand the features, mechanisms and rules of complex phenomena. For example, complexity theory has been used to evaluate the capacity for collaboration in Health Action Zones policy (Barnes et al. 2003), and CAS research is used to assess the best transition paths towards future technological innovations in industry (Franken et al. 2007). In general, applying CAS theory to other domains may help in better understanding of the mechanisms and features of complex phenomena.

This research seeks to determine whether SDIs can be viewed as CASs. We analysed three National SDI cases and conducted a survey on the complex characteristics and features that can be found in SDIs.

The remainder of this article is organized as follows: Section 2 describes the complex nature of SDI; Section 3 presents the principles of CASs theory; Section 4 explains the methodology used to meet the research objective; Section 5 states the research hypothesis that SDIs can be treated as CASs; Section 6 presents the results of the application of CAS theory to the selected national SDI cases (Australian, Dutch and Polish) and the results of the survey of SDI experts on the complex character of SDIs; Section 7 discusses the results of the analysis of the case studies and survey responses, presents some implications of these results and makes recommendations for further research on exploring and evaluating SDI; Section 8 describes the conclusions of the research.

2. The complex nature of SDIs

Many authors have already indicated that SDIs have a tendency to become complex (Chan and Williamson 1999, De Man 2006, Georgiadou et al. 2006). The first SDIs, called first-generation SDIs (Rajabifard et al. 2003), concentrated mainly on data storage, access and exchange. The complexity of those early SDI initiatives was mainly technological in nature. The second-generation SDIs brought an increase in the numbers of users, applications and requirements. SDI functionality became more complex (Chan and Williamson 1999), as facilitating the interaction between data and people became a focal point of the SDI concept (Rajabifard et al. 2002). An SDI can therefore be seen as a sociotechnical assembly rather than simply a technical tool (De Man 2006). The variety of SDI actors and the intensity of interactions between them is one of the potential reasons for the complexity of such assemblies. As new SDI applications emerge the organizational structure grows and thus the number of people involved and the relations between them increase. As this progresses
the initially complicated SDI becomes rather complex. Moreover, complexity also arises as SDIs shift from being data-centric to service-centric infrastructures (Georgiadou et al. 2006). Following initial enthusiasm about the applicability of SDIs to help solve problems in a vast number of domains, it became clear that creating and managing SDIs is not easy. Even the large number of definitions of SDI illustrates the high level of disagreement among stakeholders about its nature.

It is important to discuss in more detail the role of the human factor in SDIs because people are probably the main reason for SDI complexity. The architecture of an SDI depends heavily on the nature of the environment in which it develops, especially the people who design, implement and work with it. Their experience, expertise, culture and objectives play a crucial role. Publications like the SDI Cookbook (Nebert 2004) provide useful guidance, but in practice following the same recipe for building SDIs in different environments usually leads to different and often unexpected results. Moreover, in the course of time people may change the SDI concept. For example, one of the main rationales behind the transition from a product-based to a process-based model (Masser 1999, Rajabifard et al. 2003) was that SDI users and producers realized that the potential of SDI goes beyond simply managing data. The introduction of web services, increased data sharing between users and the shift in focus towards the use of data were the main drivers behind the evolution of SDI towards a process-based model (Crompvoets 2006). Those changes and the evolution of SDI are only possible because people play a key role in the SDI concept. Referring to Rajabifard et al.’s (2002) SDI conceptual model (see Figure 1), it has to be stressed that people are not limited to one side of the diagram as a separate component, but are rather an integral part of all other components, especially technology, policy and standards, and the human factor plays a key role in shaping those components: people develop the technology behind access network facilities; policies on SDI are solely created and obeyed by people; standards can only be developed and applied successful if people reach agreement. One of the key provisions of SDI is to improve spatial data sharing between individuals and organizations. Spatial data sharing depends mainly on social and cultural aspects because it requires agreements on common definitions and standards (Calkins and Weatherbe 1995, Omran 2007). SDI development requires an increase in a number of people to cope with the growth, but increasing the number of people results in an even faster increase of the number of possible communication channels (e.g. increasing the number of people from 2 to 4 increases the number of communication channels from 1 to 6). This effect might explain why human systems (including SDIs) become so difficult to manage as the number of stakeholders increases. For all these reasons, the human component of SDI is probably the main reason for its complex nature.

Figure 1. SDI components.
Source: Rajabifard et al. 2002.
The complex nature of SDIs is the reason for the difficulties encountered in trying to understand and assess them. The lack of knowledge on how to deal with the complexity of SDIs makes its assessment difficult. For example, it is difficult to attribute success or failure to one or more concrete factors. In other words, because SDIs are complex it is difficult to track cause-and-effect relationships (Rodriguez-Pabon 2005). Moreover, the dynamic and uncertain relations between the SDI building blocks – data, policies, standards, technologies and people – are hard to predict and control. In every part of the world, regional, national and local SDIs have a unique character and behave differently. This makes it difficult to implement SDIs in different environments in the same way and with the same outcomes. It has become clear that a proper understanding of SDI requires research that draws on knowledge from various fields, including technological, legal, economic, social and organizational domains.

Eoyang (1997) distinguishes two paradigms which can be used to analyse various phenomena: (1) Newtonian approaches and (2) complex approaches. The Newtonian approaches assume that the phenomenon is predictable, that certain procedures will lead to certain objectives, that the final outcome of the phenomenon performance is a sum of the performance of its parts, etc. In contrast, the complex approaches acknowledge uncertainties in a system due to emergent mechanisms in its functionality, the flexibility of system structures and adaptability to external conditions. They also acknowledge complexity rather than trying to simplify it. The choice of the approach depends on the characteristics of the phenomenon to be analysed (see Table 1).

The choice of paradigm does not have to be mutually exclusive: Newtonian and complex approaches can also be used simultaneously. SDIs are quite new (less than two decades of development), not well defined, not fully explored, changing, not solved and the outcomes are not well known. Therefore, the choice of the complex approach to analyse SDI is justified.

Understanding SDIs as CASs could help in identifying the mechanisms and forces that shape SDI development and in finding the best assessment strategy for SDI. The next section explains the concept of CASs in more detail.

3. **Complex adaptive systems**

CASs have their roots in the study of chaotic systems (Gleick 1989, Lorenz 1993). Studies of various systems in different disciplines led researchers to focus on systems that moved from stable, predictable patterns into unstable, unpredictable behaviour (Kiefer 2006). Results from further studies led researchers to identify two groups of chaotic systems:
(1) unpredictable systems and (2) systems that moved through unpredictable states into new, more complex patterns of behaviour. The latter group has attracted attention from a wide group of researchers as CASs (Waldrop 1992, Eoyang 1996, Cilliers 1998, Eoyang and Berkas 1998, Holland 1998). Intensive pioneering research on the concept of CASs was conducted at the independent Santa Fe Institute (SFI) for multidisciplinary collaboration. Many other scientists subsequently became interested in the concept of CAS and its applications, leading to the creation of many research groups at various scientific institutes all over the world devoted to complexity related research.¹

CASs are defined in many different ways. For the purpose of this research we will use the following definition: ‘CASs are open systems in which different elements interact dynamically to exchange information, self-organize and create many different feedback loops, relationships between causes and effects are nonlinear, and the systems as a whole have emergent properties that cannot be understood by reference to the component parts’ (Barnes 2003).

CASs have a specific number of features and behaviours that make them distinctive from other types of systems. The features are the set of system characteristics that together make CASs different from other systems. Similarly, CAS behaviours are the distinctive collection of system activities and processes that make CAS behaviour unique. The collection of CAS features and behaviours used in this research is based on many resources on complex systems (Waldrop 1992, Eoyang 1996, Cilliers 1998, 2005, Eoyang and Berkas 1998, Barnes et al. 2003, Rotmans 2005). Because the CAS literature we reviewed contained variations and differences in the number and names of the CAS features and behaviours, for the purpose of this research we limited the list to those CAS features and behaviours that were common to the literature sources reviewed.

3.1. CAS features

3.1.1. Components

CASs always consists of relatively stable and simple building blocks (Cilliers 2005) that are linked via mutual interactions (Eoyang and Berkas 1998, Rotmans 2005). Holland (1998) states that building blocks are a pervasive feature of CASs.

3.1.2. Complexity

The system’s behaviour emerges because many of the simple components interact simultaneously (Waldrop 1992, Cilliers 2005). In principle, this means that there is a constant exchange of information and needs between the components and the actors in the system. Complexity also means that the whole of the system is different from the sum of its parts (Eoyang 2004); complex systems cannot be analysed only by examining their parts separately.

3.1.3. Sensitivity to initial conditions

In CASs a small initial action may have a major effect in the future. Very small difference in the initial state of the system may result in a big change in the outcome. For example, changes to a single legal document may have a major effect on many organizations, or even on society as a whole.
3.1.4. **Openness**
CASs interact with their environment (Rotmans 2005) and are susceptible to external influences (Eoyang and Berkas 1998). It is also difficult to define clearly where the boundaries of complex and adaptive systems are (Barnes et al. 2003).

3.1.5. **Unpredictability**
It is hard to be sure about the final outcome of the system’s behaviour. The unpredictability of CASs is a result of many actors taking independent actions that subsequently influence other actors and their actions. To make sense of the output of the complex system we must take into account the mechanisms by which it is produced (Cilliers 1998). However, predictions can never be made with certainty.

3.1.6. **Scale independence**
Different hierarchical levels of CASs have a similar structure (the ‘fractal building’). This feature can be found in organizations where the same characteristics (e.g. functional dependencies, relations between employees, policies and rules) can be seen from the bottom to the top of the management chain (Eoyang and Berkas 1998).

3.2. **CAS behaviours**

3.2.1. **Adaptability**
As part of the wider environment, CASs are able to adjust and adapt themselves to external influences (Cilliers 2005, Rotmans 2005). For example, increasing concurrence in the sector may force a particular company or organization to adapt by changing its organizational model to a more efficient one. However, system adaptability may also be a result of internal factors, like the operation of a system’s memory: the system may change as it learns from its own experience. According to Holland (1998), adaptation can also be described as a change in the system’s structure (strategy) resulting from the system’s experience.

3.2.2. **Self-organization**
The ability of CASs to develop a new system structure by themselves is a result of their internal constitution and not a result of external management (Rotmans 2005). According to Eoyang (1996), a system self-organizes if it is pushed far enough away from its equilibrium state. Examples of self-organization in human systems are spontaneous group activities, like revolts. Cilliers (1998) defines self-organization as a process in which a system can develop a complex structure from fairly unstructured beginnings. The process occurs under the influence of both the external environment and the history (memory) of the system.

3.2.3. **Nonlinear behaviour**
In CASs it is difficult to determine the value of a second variable, even when a first variable is known (Eoyang 1996). Changes are prompted by external or internal factors boosting or slowing the system down. Cillers (2005) explains this nonlinearity by describing interactions as dynamic input–output relations. This means that the strength of interaction changes over
time. For example, changes in political strategies may have a causal influence on CAS behaviour or development.

3.2.4. Feedback loop mechanism

The system has a tendency to use its own output to adjust its inputs and processes (Eoyang 1996). Two types of feedback loops can adjust the behaviour of CAS: negative and positive. The evaluation process is an example of a feedback loop, which may be either positive or negative. It is positive when the system learns from the evaluation and enhances its performance and negative when negative evaluation results discourage programme participants. If designed properly, positive feedback mechanisms facilitate change and adaptation of the system (Patton 1990).

4. Methodology

To determine whether SDIs can be viewed as CASs, we followed three research steps. First, the common features and behaviours of most CASs were identified. The CAS features and behaviours presented in Section 3 were selected in two steps: (1) from the rigorous review of CAS literature we collected all CAS features and behaviours; (2) we reduced the number of features and behaviours to those that were common to all CAS literature.

Second, we followed a case study research method to empirically identify CAS features in three national SDIs. The pattern-matching technique (Yin 2003) was used to analyse the case study evidence. The technique was applied in the following way: A hypothesis stating that an SDI is a CAS was made. The hypothesis assumes that certain CAS features and behaviours (patterns) are present in SDI cases (see Section 5). These hypothetical patterns were then compared with the empirical evidence from the case study analysis and summarized in a table (see Table 3). If there was strong evidence for a pattern match, we assigned an ‘in agreement’ label. For weaker evidence we assigned a ‘neutral’ label. Where the case study analysis revealed a different pattern than the one suggested by the hypothesis, we assigned a ‘not in agreement’ label. In some cases we could not find any information on CAS features and behaviours in the SDI case studies. In those cases we assigned a ‘no information’ label.

The rationale for using the case study method for this research was based on four conditions for selecting case study as a useful strategy for conducting research (Pare 2004): (1) the phenomenon is complex; (2) the existing body of knowledge does not allow us to pose causal questions; (3) holistic and in-depth investigation is needed; (4) the phenomenon cannot be studied outside its context. At least the first three conditions are valid for SDIs as they are complex and the mechanisms behind them are not fully understood, which makes it difficult to pose causal questions. Moreover an in-depth investigation of the whole SDI is needed to be able to identify CAS features and behaviours. Case studies of three national SDIs (NSDIs) – from Australia, the Netherlands and Poland – were chosen for practical reasons. The case study approach requires in-depth analysis of the documents, which usually are written in the national language and all of them could be accessed and understood by the authors of this study. Additionally, the three cases represent three different approaches to setting up and operating SDIs: very hierarchical (Poland), voluntary (the Netherlands) and a mix of the two (Australia). Each NSDI case description was reviewed by a key SDI contact person for that country to confirm the validity of the facts. These key people are actively involved in the development and coordination of the NSDI in their country.
Third, an anonymous Internet-based survey was carried out. The survey was sent to 33 participants of the ‘Multi-view framework to assess National Spatial Data Infrastructures’ workshop held at Wageningen University in 2007 (Crompvoets and Grus 2007). The workshop main topic was the SDI assessment. It also included one presentation in which the potential relationship between SDI and CAS was mentioned. As a survey population 33 participants were selected out of a total of 45 participants because they attended the workshop the full three days and as a result they received a similar amount of information. All workshop participants were professionally closely related to SDI. Table 2 describes the characteristics of the survey population.

The workshop participants were asked to express their strength of support for 21 statements about the presence of six CAS features and four behaviours in SDI. The statements were formulated in such a way that the survey respondents could agree or disagree with them using the following scale: strongly agree, agree, neutral, disagree and strongly disagree. Each CAS feature or behaviour was described in its SDI context by two statements. In addition, the workshop participants were asked whether a SDI can also be described as a ‘system’, the definition of which was adapted from the Longman Dictionary of Contemporary English (LDOCE 1995). The questionnaire focused on the overall concept of SDI and did not specify any particular SDI levels, such as national, local or regional. The Internet-based survey was performed 10 months after the workshop. The survey objective, which was to check CAS features and behaviours in SDI context, was not mentioned to the respondents. The survey questions were also formulated in a neutral way asking respondents about their opinion about some SDI characteristics so they could not know that the questions were about to check SDI and CAS similarity. Therefore, we assume that the respondents were not biased by the past workshop. The questionnaire and respondents’ answers can be found in Appendix 1.

5. Hypothesis

The hypothesis that we tested is: ‘Spatial Data Infrastructure can be viewed as a Complex Adaptive System’. The truth of the hypothesis is highly probable if CAS features and behaviours can also be identified in SDIs. On the basis of the proposed hypothesis, the following features and behaviours, similar to those found in CASs, are also expected to be present in SDI:

- SDI consists of a number of identifiable components.
- SDI is a complex phenomenon because it consists of many components and multiple actors which constantly interact with each other.
SDI is sensitive to initial conditions, i.e. decisions made about SDI at the initial stage of its development may have an impact on its future development.

SDI is open because it interacts with (i.e. adapts to, has influence on, learns from) other sectors. SDI is also open as it is very difficult to define its boundaries.

SDI is unpredictable because we cannot be sure how it will look and how it will function in the future.

SDI architecture is self-similar on different levels of the hierarchy. For example, in both local and national SDIs, it is possible to identify similar building blocks (data, policies, standards, etc.). Each building block also has a similar function in either local, regional or national SDIs.

SDI is able to adapt its own structure and functions to new user or market requirements and demands. It is also able to incorporate new technologies that emerge in other sectors and might be beneficial for SDI.

SDI is able to self-organize (or self-regulate) which is the result of communication, interaction and learning from past actions. Bottom-up activities and initiatives to improve SDI (e.g. the rapid response of the SDI community to emerging user needs and requirements) might indicate the self-organizing ability.

SDI behaviour is nonlinear in such a way that its development may be disturbed by internal and external factors (e.g. a lack of political support for SDI may slow down its development or push it in a different direction). As a result, the intended SDI objectives might not be met.

SDI has feedback loop mechanisms which enable it to learn from its own experience. For example, stakeholders may use performance or output assessments to refine their actions towards developing SDIs. Evaluation, innovation and scientific programmes embedded in SDIs that emerge during its development might indicate the existence of feedback mechanisms.

6. Results

This section presents the research results. Section 6.1 presents the results of the case studies analysis. Each case analysis starts with a description of the SDI case, followed by a short description of each CAS feature and behaviour in the context of the SDI. Section 6.2 presents the results of the survey on similarities between CAS and SDI.

6.1. Case studies

6.1.1. The Australian NSDI as CAS

The facts about the Australian SDI (ASDI) are mainly based on Clarke et al. (2003), Chan et al. (2005), Warnest et al. (2005), Department of Industry, Tourism and Resources (DITR) (2004) and Blake (2005).

The beginnings of ASDIs lie with the Australasian Urban and Regional Information Systems Association – AURISA (presently part of Spatial Sciences Institute – SSI). In the late 1970s and 1980s AURISA was a major catalyst for bringing together state agencies to discuss land information systems. Those efforts energized other states, local governments and finally the national government. In 1986, by agreement between the prime minister and the heads of the Australian state and territory governments, an Australian Land Information Committee was established. In 1991, it became the Australian and New Zealand Land Information Committee (ANZLIC) and since 2004 it has been known as ANZLIC – The
Spatial Information Council. Its formation was a response to the growing need to coordinate the collection, transfer and promotion of land-related information. ANZLIC’s role is to establish policies, standards and guidelines to facilitate access to spatial data and services provided by many organizations dispersed across the country. ANZLIC coordinates the development of the ASDI through its vision that recognizes that Australia’s spatially referenced data, products and services should be widely available and accessible to users. The Australian and New Zealand governments are each responsible for coordinating spatial information policies in their jurisdictions; ANZLIC encourages the coordination of activities which are of national importance via ANZLIC representatives that reside in each jurisdiction. At the national level, GeoSciences Australia is a Commonwealth government agency that collects and maintains small-scale mapping and spatial datasets. Several other bodies have emerged in the recent years, strengthening the public, private, professional and research SDI organizational infrastructure. At the national level the key ASDI players are

- ANZLIC, an intergovernmental SDI coordinating agency;
- Public Sector Mapping Agency (PSMA), a public company that integrates critical spatial data from governmental sources (national and from each jurisdiction) to support spatial data users. PSMA plays an important role in ASDI because it builds national spatial data from Commonwealth or state/territory data and utilizes them via the network of value adders. PSMA’s chair is also a member of ANZLIC;
- Australian Spatial Information Business Association (ASIBA), a professional association that aims to represent industry’s spatial information needs and interests;
- SSI, a national body providing a forum for professional people in the spatial information industry in Australia. In the near future it will be named Surveying and Spatial Sciences Institute;
- Centre for SDI and Land Administration at the University of Melbourne, research centre established in 2001 within the Department of Geomatics. Its research focuses on designing and developing SDI, spatially enabling government and society, cadastral system, land management, etc.
- Cooperative Research Centre for Spatial Information (CRC-SI), which undertakes spatial information-related research in location, image analysis, spatial information systems, remote sensing, etc.;
- The Australian Spatial Consortium (ASC), a consortium supported by CRC-SI whose objective is to unlock and utilize the potential of spatial information within the industry.

The ASDI framework comprising the aforementioned players operates through consensus. The Commonwealth has not adopted any legal requirements or pressured the actors within the ASDI in any way.

6.1.1. Components. ANZLIC’s definition of ASDI recognizes people, policies and technologies as SDI components. According to this definition, these components are necessary to enable the use of spatially referenced data at all levels of government, the private and non-profit sectors and academia.

6.1.1.2. Complexity. The complexity of ASDI arises from the requirement for cooperation between the national government and the nine state governments. Moreover, the large number and diversity of players who constitute and contribute to ASDI often have different needs, but have to interact and cooperate with each other. This makes the
situation even more complex. This complexity, however, is managed by an organizational structure coordinated by ANZLIC.

6.1.1.3. Sensitivity to initial conditions. The Australian state agencies for spatial data focused quite naturally on high-resolution data covering their state territory. Because of AURISA’s initial activities in bringing together those state agencies to create ASDI (see case description), the present ASDI can be characterized by relatively strong role of state SDIs and easy availability of high-resolution datasets.

6.1.1.4. Openness. The creation of the ASC (see case description) to make use of the potential of spatial information in other industrial domains suggests that ASDI is open to interaction with other sectors. Also, the existence of ASIBA, which represents the interests of industry in spatial information, is some evidence that ASDI reaches out beyond its own organizational boundaries and that SDI applications can serve the real needs of industry. ASDI is also open to its international environment through the active membership of ANZLIC in the Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP), a regional SDI initiative.

6.1.1.5. Unpredictability. ANZLIC’s strategic plan and work programme is defined until 2010. It is still unknown what will happen after this date: whether all the intended outcomes have been achieved. The future of ASDI after 2010 cannot therefore be predicted with much certainty. However, the relatively widespread recognition of SDI benefits and the existence of many independent bodies playing different roles in the ASDI suggest that its existence is not in any real danger in the near future. This strong acceptance of the SDI concept in Australia reduces its unpredictability.

6.1.1.6. Scale independence. ASDI can be characterized by a clear division between national and state or territory SDIs. Replication of the SDI model from the higher ASDI level (ANZLIC) to lower state levels (represented by the Australian Capital Territory Planning and Land Authority, the New South Wales Department of Lands, the Northern Territory Department of Planning and Infrastructure and others) is evidence of the scale independence of ASDI. In other words, similar organizational structures and roles are present on all ASDI levels (from local, through state to federal). Such hierarchical capability for SDI helps to exploit the main benefits of the concept because SDI challenges faced at the national level (e.g. standards implementation, data access policy, data-sharing models) may be similar to those at state or territory levels.

6.1.1.7. Adaptability. Initially ANZLIC focused mainly on land administration (cadastral) systems. Later, as the general SDI concept was maturing, ASDI recognized the much broader potential of the ASDI and changed its goals and objectives. It adapted to broader market requirements by changing the scope of its activities from narrower ‘land-related information’ to broader ‘spatial information’.

6.1.1.8. Self-organization. The heterogeneity of players in the ASDI and its openness to external factors facilitates the flow of information and energy and thus allows the system to self-organize. ANZLIC was established in response to the need to coordinate the provision of land information, and the ASDI framework was developed as a distributed system in which multiple state/territory agencies operate their own SDIs. The Commonwealth does not have any legal powers to force other players to comply with national policies or standards. Given that the ASDI
has been created mainly through consensus and in a very distributed environment, its capacity for self-organization is rather high. Moreover, the recognition of the geographical information (GI) sector’s needs and the emergence of new bodies from within the ‘spatial community’ in recent years indicate that the ASDI has a high self-organizing potential.

6.1.1.9. Nonlinear behaviour: No information that matches this CAS behaviour has been found.

6.1.1.10. Feedback loop mechanism. Each year ANZLIC reports on its performance in coordinating and implementing the ASDI. These activities form a kind of formalized feedback mechanism that is an integral part of ANZLIC’s activities. Moreover, activities like those of Cooperative Research Centre for Spatial Information (CRC-SI), which recognized the need to carry out the Spatial Information Action Agenda as a critical step in developing ASDI, can be regarded as a feedback loop mechanism. This feedback mechanism boosted the development of the ASDI by supporting and enhancing national research priorities related to spatial sciences. Another example of a feedback loop mechanism was ANZLIC’s decision to audit the Australian Spatial Data Directory (ASDD) to check the quality of the metadata. This audit resulted in a number of recommendations for improving the quality of the ASDI.

6.1.2. The Dutch NSDI as CAS


The development of the Dutch NSDI dates back to 1990 when Ravi, a network organization for geo-information, was established. Initially, Ravi was an official advisory committee on land information at the Ministry of Housing, Spatial Planning and the Environment (VROM). In 1993, it became an independent consultative body for geo-information, its members being representatives from various public sector bodies. In 2007, Ravi and the National Clearinghouse for Geo-Information (NCGI) merged to form Geonovum. Geonovum is acting on an operational level of Dutch SDI organization. It is the NSDI executive committee in the Netherlands with the task of coordinating the development of the NSDI and providing better access to geo-information in the public sector. On a strategic level, the GI-council, established in 2006, advises the Ministry VROM on strategic actions relating to geo-information sector.

The development of the Dutch NSDI can be described as a combination of many bottom-up initiatives, with some form of central coordination. For example, the ministry of VROM has taken on the role of formal geo-coordinator. However, the NSDI initiative has always been left to develop through a process of self-regulation by the GI sector, which has no formal powers to compel public agencies to participate in the Dutch NSDI. In 1992, Ravi presented a structure plan for land information that soon turned out to be a vision for the Dutch NSDI. The idea was to draw up agreements between authorities to facilitate the exchange of core registers. By the end of 2002 the objectives of the vision had almost been achieved. The next stage in the development of the Dutch NSDI is described in a new vision document called GIDEON (VROM 2008), which is adopted by the Dutch Government.

6.1.2.1. Components. The components of the Dutch NSDI are recognized in the definition of the NSDI: The National Geographic Information Infrastructure (NGII) is a collection of
policy, datasets, standards, technology (hardware, software and electronic communication) and knowledge, providing the user with the geographic information needed to carry out a task.

6.1.2.2. **Complexity.** In 2002, the Dutch Council of Ministries agreed to invest €20 million in the ‘Space for Geo-Information’ innovation programme (Ruimte voor Geo-Informatie, RGI) to improve the current geo-information infrastructure and stimulate the necessary innovation for the future. The number of partners involved in the programme related to the GI sector and SDI development is about 200. Additionally, the GIDEON vision document was drawn up through the cooperation and commitment of 21 SDI-related organizations. The high number and diversity of Dutch GI players and the coordination of their actions make the Dutch GI community very complex.

6.1.2.3. **Sensitivity to initial conditions.** Ravi was initially an advisory body of the ministry of VROM. This initial close connection to the ministry might be the reason why governmental bodies continue to give strong support to the GI initiatives and still recognize its importance, which has allowed the GI sector to develop more easily. Despite the reorganization of the SDI coordinating bodies (e.g. from Ravi to Geonovum), the people who were initially involved in the creation of the Dutch NSDI at the beginning of the 1990s are still involved and the model of cooperation that stresses the importance of bottom-up initiatives and voluntary actions still persists today.

6.1.2.4. **Openness.** The openness of the Dutch NSDI is expressed in its cooperation with a wide range of parties. Ravi (now Geonovum) even found supporters of the vision outside the geo-information sector, especially in the Ministry of the Interior. The Dutch NSDI is also open to regional SDI initiatives like the EU INSPIRE Directive and cross-border projects with Germany. The mission of the Dutch knowledge project ‘Space for Geo-Information’ is to create ‘a geo-information network that will be more dynamic and open’ within the next 10 years. This means that the network has to be flexibly integrated with adjacent disciplines, has to exchange knowledge and has to cooperate with them.

6.1.2.5. **Unpredictability.** The unpredictability of the NGII is exemplified by the knowledge project ‘Space for Geo-Information’, which is based on the premise that there is no sense in looking at GI development beyond a 10-year time horizon because of its short history and probable unpredictability. However, there are currently activities underway with the aim of continuing the ‘Space for Geo-Information’ initiative after the initial 10-year period. Moreover, the great number of SDI-related activities in both the public sector and the private sector provide sufficient grounds to be confident that the Dutch NSDI will continue in future.

6.1.2.6. **Scale independence.** Local or institutional SDIs usually comprise the same components as those listed in the definition of the Dutch NGII. For example, Geodesk, an SDI created by the research institute Alterra, has the same components (data access facility, standardization and policy) and has the same functions (improving access to data and data sharing) as those defined for the NSDI. However, because its highly decentralized structure makes it hard to identify hierarchical levels in the Dutch NSDI, we cannot conclude that the scale-independence feature is present at various hierarchical SDI levels.

6.1.2.7. **Adaptability.** An example of the adaptability of the Dutch NSDI is the introduction by Geonovum of a new prototype of the Clearinghouse that provides access to the Dutch Web Mapping Service, which complies with OGC standards. It is already the
fourth version of the Dutch Clearinghouse. Each version embraces emerging new IT technologies that can be used in SDI clearinghouse implementations. Moreover, the concept behind the clearinghouse is adapted with each new version – from being a central (meta)data repository to a network of data providers. The possibility of displaying some of the available date layers in Google Earth exemplifies how the clearinghouse capabilities are being adapted to the emerging new technologies (i.e. Google Earth) in the GI sector.

6.1.2.8. **Self-organization.** According to Masser (2005), the Dutch NSDI falls into the category of NSDIs that have grown out of existing GI coordination activities. Bottom-up processes play a crucial role in its development. For example, the new SDI policy document GIDEON, which sets out a vision, strategy and implementation plan for the Dutch NSDI, was initiated and created by the main SDI stakeholders and commented on by the relevant government departments and governmental bodies. The Dutch NSDI development model can therefore be described as voluntary rather than mandatory. Ravi (since 2007 Geonovum) has no legal powers, but this does not discourage the stakeholders from basing their SDI development activities around it. We may conclude, therefore, that the success of the NGII in the Netherlands lies in the strong self-organizing ability of the GI community.

6.1.2.9. **Nonlinear behaviour.** The nonlinearity of the development of the Dutch NSDI is only visible in some of its aspects. Emerging new technologies were one of the reasons for the relatively unstable development of the Dutch Clearinghouse (for example, the failure of the NCGI). However, the pursuit of the objectives of the first NSDI strategy went according to plan. It was therefore relatively linear.

6.1.2.10. **Feedback loop mechanism.** The ‘Space for Geo-Information’ innovation programme can be regarded as an outcome of a feedback mechanism within the Dutch NSDI. Following the successful execution of the first NSDI vision, the NSDI community and the government recognized the need for further research and the development and the creation of a new vision for the Dutch GI sector. This resulted in the investment of €20 million over a period of 10 years to improve the performance and stimulate the further development of the GI sector.

6.1.3. **The Polish NSDI as CAS**

The facts about the Polish NSDI have been drawn mainly from IGiK (2001) and SADL (2007). The Polish NSDI has been under development for many years, but its status and structure are still unclear. The first SDI-like initiatives started in the 1970s, when the National Land Information System was first put into effect. During the 1980s, the system changed and adapted to the conditions of the market and the economy (Gazdzicki and Linsenbarth 2004). These initiatives came to an end due to the many organizational, administrative and political changes over the following two decades, but now the Polish NSDI initiative is emerging again. Under the Geodetic and Cartographic Law, coordination of the NSDI in Poland was entrusted (however not in a straightforward way) to the Surveyor General of Poland, the director of the Head Office of Geodesy and Cartography (GUGiK). Most of the other bodies participating in the Polish NSDI are representative bodies for geodetic and cartographic services (the Association of Polish Surveyors, the Association of Polish Cartographers, the Institute of Geodesy and Cartography, the Polish Spatial Information Association and the National Association of GI Systems Users GISPOL). The coordination activities are funded by the Ministry of Infrastructure. The National Land Information System Decree defines the scope and content of the NSDI and bodies responsible for its establishment and
management. The NSDI is defined by the Geodetic and Cartographic Law as a database, procedures and techniques for collecting, updating and disseminating spatial data. It consists of two types of components: core components (reference datasets), managed by the Surveyor General, and thematic components, managed by various ministries. The current status of the Polish NSDI can be characterized as a patchwork of more than 100 spatial information systems at different administrative levels across the country. One of the objectives of the NSDI should be the integration of those initiatives, but the degree of coordination is not clear. Between 1998 and 2000 a research project titled ‘The Concept of the Polish Spatial Information System’ was commissioned by the Ministry of the Interior and Administration. Its goal was to propose a general concept for the NSDI in Poland. So far progress with putting the postulates of this research into effect has been limited and marginal.

6.1.3.1. Components. The Geodetic and Cartographic Law defines the NSDI as a spatial data database and techniques and procedures for the systematic collection, updating and dissemination of datasets. To some extent these three defined building blocks – database, techniques and procedures – can be regarded as components of the Polish NSDI.

6.1.3.2. Complexity. The dynamic and heavily entwined relationships, and especially the different and often contradicting interests of many of the key NSDI players and institutions, are evidence of the complexity of the Polish NSDI. Besides, the task of coordinating 100 spatial information systems dispersed across the country is complex enough without these additional complications.

6.1.3.3. Sensitivity to initial conditions. Sensitivity to initial conditions has been apparent in the Polish NSDI since its beginnings. Pre-NSDI initiatives had always taken place mainly within the geodetic domain, and the geodetic community still has the strongest influence on the Polish SDI scene.

6.1.3.4. Openness. The knowledge and experience of the geodetic community and related organizations cannot be questioned. However, their dominance in activities for the creation of the NSDI in Poland can hinder its openness to cooperation with other domains and other non-geodetic players. For example, one of the objectives of the GISPOL association of GI users, which has its roots in geodesy, is to ‘oppose the diffusion of geodetic datasets’ or to ‘give preference to the supporters of its actions’. This raises questions about the openness of geodetic bodies, and thus the NSDI, to other players from other domains.

6.1.3.5. Unpredictability. When we look back and analyse the very dynamic and promising pre-NSDI initiatives of the 1970s (the concept of Information System TEREN), the 1980s (Multipurpose Cadaster initiative) and current initiatives, it can be concluded that the development of the NSDI in Poland is very unpredictable. Most of the initiatives were suspended or not successful due to external factors like political system change or administrative reform.

6.1.3.6. Scale independence. No information that matches this CAS characteristic has been found.

6.1.3.7. Adaptability. The difficulty with adaptation is shown by the limited compliance of the Polish NSDI with the EU’s INSPIRE Directive, despite the establishment of the Rada Implementacyjna Inspire (Inspire Implementation Committee) in 2007.
6.1.3.8. **Self-organization.** The semi-formal mandate given to the Surveyor General, as the head of GUGiK, to coordinate the operation of the Polish NSDI may be some evidence of the self-organization ability of the system. However by designating to GUGiK coordination of Polish SDI tasks, geodetic organizations got relative advantage in building SDI. The attempts to formalize the creation of the NSDI by geodetic bodies leave little room for initiatives by other GI players and thus limit the self-organization mechanisms. As a result, the main Polish NSDI players are concentrated around the well-established and influential geodesy community without much opportunity for bottom-up approaches.

6.1.3.9. **Nonlinear behaviour.** The history of Polish SDI development is characterized by the emergence of many initiatives, which for a number of reasons collapsed (see also Section 6.1.3.5 above). This is evidence of very nonlinear behaviour in the Polish NSDI.

6.1.3.10. **Feedback loop mechanism.** The research project ‘The concept of the Polish Spatial Information System’ may be an example of a positive feedback loop. After a number of attempts to create an NSDI, the Ministry of Interior and Administration reflected on the lessons learned and ordered a research project with the aim of formulating a comprehensive concept for the Polish NSDI. However, due to formal and organizational constraints (no formal mechanism to carry out the postulates from the concept) the concept has not yet been implemented.

Table 3 summarizes the results of the case study analysis. The detailed discussion of these results can be found in Section 7.

### 6.2. Results of the SDI as CAS questionnaire

The intention of the questionnaire was to explore the truth of the hypothesis that SDIs can be considered to be CASs by asking for the opinion of SDI experts. From the 33 questionnaires sent, we received 27 answers (an 82% response rate). Figure 2 presents a summary of the results of the questionnaire. Detailed results of the questionnaire can be found in Appendix 1. Each bar in Figure 2 represents the level of support for the existence of CAS features and behaviours. The percentages were obtained by summing Strongly Agree (SA) and Agree (A) or Strongly Disagree (SD) and Disagree (D) responses (depending on the statement formulation) for each statement relating to a CAS feature or behaviour. The results show that the level of support for all CAS features and behaviours was more than 50%. The respondents to the questionnaire expressed the highest support for the statements that SDIs

<table>
<thead>
<tr>
<th>CAS features and behaviours</th>
<th>Australia</th>
<th>The Netherlands</th>
<th>Poland</th>
</tr>
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<tbody>
<tr>
<td>CAS features in SDIs</td>
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<td>In agreement</td>
<td>Neutral</td>
</tr>
<tr>
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<td>In agreement</td>
<td>In agreement</td>
<td>In agreement</td>
</tr>
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<td>In agreement</td>
<td>In agreement</td>
</tr>
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</tr>
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<td>In agreement</td>
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</tr>
<tr>
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<td>Not in agreement</td>
<td>In agreement</td>
</tr>
<tr>
<td>Scale independence</td>
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<td>No information</td>
</tr>
<tr>
<td>Adaptability</td>
<td>In agreement</td>
<td>In agreement</td>
<td>Neutral</td>
</tr>
<tr>
<td>Self-organization</td>
<td>In agreement</td>
<td>In agreement</td>
<td>Not in agreement</td>
</tr>
<tr>
<td>Non-linearity</td>
<td>No Information</td>
<td>Not in agreement</td>
<td>In agreement</td>
</tr>
<tr>
<td>Feedback loop</td>
<td>In agreement</td>
<td>In agreement</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
are open (96 and 78%). Statements about the sensitivity to initial conditions and the
unpredictability of SDIs also received relatively high support (89 and 78%, and 93 and
70% respectively). The self-organizing behaviour of SDIs was supported by 56% of the
respondents in the first statement and by 89% in the second statement, which was the biggest
difference in the level of support between statements 1 and 2. The existence of a feedback
loop mechanism was supported in two statements by 70 and 74% of the respondents. The
respondents expressed the lowest support to the statements suggesting that SDI is adaptable:
52 and 59%.

7. Discussion
The objective of the research was to determine whether SDIs can be viewed as CASs. To
meet this objective we used two methods: (1) analysing three case studies of NSDIs, (2)
conducting a survey on complex characteristics and features that could be found in SDIs.
Here we discuss the results of using these two methods in our research.

Most of the CAS features and behaviours (with two exceptions where no information
has been found – see Table 2) were identified in all three NSDI cases. In the Dutch and
Australian SDI case studies it was possible to identify similar CAS behaviours and features
to those stated in the research hypothesis. However, in both cases the unpredictability
feature could not be matched with the pattern typical for CAS. The possible reason for this
might be that SDIs are rather unpredictable only in their early stages. In the course of time, as the SDI concept matures and its benefits and necessity are well recognized, the continued existence of the SDI becomes more certain. This change may also occur for other CAS features and behaviours. In the Polish NSDI, which is still in its infancy compared with the Australian and Dutch NSDIs, some CAS features and behaviours are different from those in the two other NSDI cases. For example, the Polish NSDI is evidently less open and less self-organizing. This might be typical for early stages of SDI development, in which the SDI community concentrates only on its own development and is therefore rather closed.

The result of the questionnaire shows that the majority of workshop participants agree that SDIs are similar to and behave like CASs. More than half of the workshop participants agreed that all of the CAS features and behaviours can be identified in SDIs, giving the highest support to openness, unpredictable behaviour and sensitivity to initial conditions. It is important to note that the smallest number of workshop participants agreed with the adaptive behaviour of SDI and one-third of the respondents were neutral on these statements (see detailed data in Appendix 1). This could mean that the respondents do not reject the fact that SDIs are adaptable, but are not thoroughly convinced. The reasons for the large difference between the levels of support for the two statements about the self-organizing behaviour of SDI (33%) could be that one of the statements is wrongly formulated or was not clear to the respondents (see statements 7 and 21 in Appendix 1). This could also explain the inconsistency between the respondents’ answers to the statements about nonlinearity and unpredictability. For both characteristics the difference between the level of support for the first and second statements is 23%. The level of support for the remaining pairs of statements is quite consistent: the differences between the support for statements 1 and 2 vary from 4 to 18%.

The two methods that were used in this study – case study analysis and questionnaire survey – complement each other. The case studies concentrated specifically on NSDI implementations and data that were collected only from written documentation, whereas the questionnaire focused on the general SDI concept and data were collected by means of an online form filled in by SDI experts. The results of the online questionnaire confirm the findings of the case study analysis.

We must also discuss the limitations of the research methods that we used. In the case study analysis, data were collected from official documents and publications. For practical reasons not all official documents on each country’s NSDI are publicly available and neither are they available to us. Therefore we must assume that the picture we tried to draw on each NSDI might be not complete. Additionally, because the documents about each NSDI were read and interpreted by the authors of this study, the case study analysis may involve some level of subjectivity. To minimize these limitations we asked SDI experts from each country to review the text of each NSDI case and confirm the truth of the facts. The main limitation of conducting an online questionnaire survey is the possibility that the respondent misinterprets or does not properly understand the questions. In an attempt to reduce this risk, the respondents were given the opportunity to comment on each statement to allow us to identify any misinterpretations and take any comments on the nature of the statement into account.

The mix of respondents to the questionnaire suggests there may be a certain bias in the results (see Table 2). The number of respondents from the Netherlands is higher than from other countries. Moreover, the proportion of scientists in the group of respondents is high and the number of respondents from the private sector is much lower than from government and academia. Nevertheless, the survey questions were relatively abstract and not related to any sectoral domain (i.e. private, public or academic) and not related to any territory. As the
aim of the questionnaire was to gauge the respondent’s mental attitude to the questions that we asked, we assumed that the respondents’ country of origin and role they play would have a limited impact on the answers.

The research results suggest that although SDIs do not resemble CASs in every aspect, they can certainly be treated and analysed as CASs. Viewing SDI through the lens of CAS theory allows us to better explain and understand SDI. It is clear that features and behaviours such as openness, level of self-organization, adaptability and existence of feedback loop mechanisms, play an important role in the efficient and effective functioning of SDI. SDI should be able to self-organize and be open to create its own structure and to cooperate with other domains. However, without any coordinating mechanism it is difficult to successfully establish and manage an SDI. The importance of any kind of positive feedback loop mechanisms (i.e. activities that evaluate past SDI activities and set goals for its future development) cannot be underestimated. Self-organization, openness and feedback loop mechanisms provide SDI with the capacity to adapt to changes. A high degree of adaptability guarantees that an SDI can continuously develop by adjusting its structure, behaviour and goals to changing external circumstances. It is also evident that although unpredictable and nonlinear behaviour cannot be eliminated, in a well-operating SDI these characteristics can be minimized by a well-functioning coordination body and by building long-lasting societal and governmental awareness of the necessity of having and maintaining an NSDI. Defining SDI components clearly helps to systemize and manage its complex structure. Being aware of the fact that SDIs are sensitive to initial conditions might help in identifying the small factors that play an important role in shaping SDI structure. Awareness of this SDI feature could help to track the real sources of some of the problems that SDIs may face.

Viewing SDI as CAS has major implications for SDI assessment. The methods for assessing CASs require specific strategies that are different from those used for less-complicated, linear and predictable systems. Many standard assessment tools, techniques and methods rely on the assumption that the evaluated phenomenon is linear, closed and predictable. Because these assumptions may not be valid for complex phenomena such as SDI, we should consider a number of principles underlying the assessment of CASs (Eoyang and Berkas 1998). For example, the assessment framework should be flexible because CASs are not stable and their baseline (objectives, definition, etc.) may change over time. The assessment framework should also include multiple strategies and approaches to allow assessment from many different perspectives. Cilliers (1998) and De Man (2006) argue that complex problems can only be investigated using complex resources such as multifaceted views. Therefore, when analysing complex phenomena such as SDI we should not try to simplify the complexity, but acknowledge it and deal with it. Oversimplification of the assessment framework should be avoided because it might not reflect the complexity and variability of the assessed phenomena. We therefore recommend that the results of this research be taken into account when designing an SDI assessment framework.

8. Conclusions

The complexity of SDIs has become a generally accepted fact, but so far little is known about what to do with this fact. This research provides a new insight into the mechanisms and functionality of SDIs from the perspective of CASs. By means of case study analysis and consulting experts it was possible to investigate the possibilities of using CAS theory to describe SDI. Most of the characteristic features and behaviours of CASs could also be identified in SDIs. On the basis of such evidence, we can conclude that CAS theory is applicable to describe SDI.
The fact that an SDI can be viewed as a CAS has implications for various studies regarding SDI, especially its assessment. New assessment strategies, preferably derived from the research on complex systems, should be further investigated with a view to their possible application in SDI assessment to improve the validity of such assessments. In addition, the in-depth analysis of CAS features and behaviours identified and analysed in this study may lead to a better understanding of SDIs.

Acknowledgements

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Note


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Spatial Application Division, Catholic University of Leuven (SADL), 2007. Spatial data infrastructure in Europe: state of play during 2005, Poland.


### Appendix 1

**Abbreviations:**

- **SA** Strongly Agree
- **A** Agree
- **N** Neutral
- **D** Disagree
- **SD** Strongly Disagree

<table>
<thead>
<tr>
<th>Questionnaire results on Spatial Data Infrastructures as Complex Adaptive Systems</th>
<th>Responses</th>
<th>%</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SDI consists of recognizable components. (Components)*</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>7.4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>59.3</td>
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</tr>
<tr>
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<td>14.8</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>11.1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>7.4</td>
<td>2</td>
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</tbody>
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(Continued)
### Questionnaire results on Spatial Data Infrastructures as Complex Adaptive Systems

<table>
<thead>
<tr>
<th>Question</th>
<th>Responses</th>
<th>%</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. SDI is isolated from its environment. (Openness)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td></td>
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<td>0</td>
</tr>
<tr>
<td>A</td>
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<td>D</td>
<td></td>
<td>42.3</td>
<td>11</td>
</tr>
<tr>
<td>SD</td>
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<td>53.8</td>
<td>14</td>
</tr>
<tr>
<td>3. Decisions on SDI made in the past have an impact on its future</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>development. (Sensitivity to initial conditions)*</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td></td>
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</tr>
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<td>SD</td>
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<tr>
<td>4. New SDI functions can emerge in the future. (Unpredictability)*</td>
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<tr>
<td>5. The main SDI components are similar on different levels of SDI</td>
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<tr>
<td>hierarchy, e.g. Local SDIs, National SDIs (Scale independence)*</td>
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<td>SA</td>
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<tr>
<td>6. SDI’s future activities can be predicted with high certainty.</td>
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<tr>
<td>(Unpredictability)*</td>
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<tr>
<td>SD</td>
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<td>7.4</td>
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<tr>
<td>7. SDI organizers may create their own organizational structure without</td>
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<tr>
<td>necessarily being guided by an external, non-SDI body. (Self-organization)*</td>
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<td>SA</td>
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<td>SD</td>
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<tr>
<td>8. SDI behaviour may change in an unpredictable way due to</td>
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<tr>
<td>transformations in country’s political strategies. (Non-linearity)*</td>
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### Questionnaire results on Spatial Data Infrastructures as Complex Adaptive Systems

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<th>Responses</th>
<th>%</th>
<th>Number</th>
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<tbody>
<tr>
<td>9. SDI is able to learn from its own experience and improve itself, i.e. by changing its organizational structure to a more efficient one. (Feedback loop)*</td>
<td>SA</td>
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<td>2</td>
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<tr>
<td></td>
<td>A</td>
<td>63.0</td>
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</tr>
<tr>
<td></td>
<td>SD</td>
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<td>0</td>
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<td>10. It is difficult to identify SDI’s main building blocks. (Components)*</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>SD</td>
<td>11.1</td>
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<tr>
<td>11. Complexity of SDI is a result of many actors constantly interacting with each other in a way which is hard to predict. (Complexity)*</td>
<td>SA</td>
<td>19.2</td>
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</tr>
<tr>
<td></td>
<td>A</td>
<td>50.0</td>
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</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.8</td>
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<tr>
<td>12. Current SDI performance is independent of the decision made about it in the past. (Sensitivity to initial conditions)*</td>
<td>SA</td>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>SD</td>
<td>11.1</td>
<td>3</td>
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<tr>
<td>13. It is not easy to determine the boundaries of SDI. (Openness)*</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>SD</td>
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<td>0</td>
</tr>
<tr>
<td>14. SDI is able to change its own structure and strategies over time due to changing circumstances in its environment. (Adaptability)*</td>
<td>SA</td>
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<tr>
<td></td>
<td>A</td>
<td>55.6</td>
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</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.7</td>
<td>1</td>
</tr>
<tr>
<td>15. On different SDI’s hierarchical levels the constituting components are similar. (Scale independence)*</td>
<td>SA</td>
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<tr>
<td></td>
<td>A</td>
<td>59.3</td>
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<tr>
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(Continued)
## Appendix (Continued)

Questionnaire results on Spatial Data Infrastructures as Complex Adaptive Systems

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<tr>
<th>Responses</th>
<th>%</th>
<th>Number</th>
</tr>
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<tbody>
<tr>
<td><strong>16. SDI is able to adapt its functionality to the emerging advancements in other sectors. (Adaptability)</strong></td>
<td></td>
<td></td>
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<tr>
<td>SA</td>
<td>3.7</td>
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</tr>
<tr>
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<tr>
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<td>D</td>
<td>11.1</td>
<td>3</td>
</tr>
<tr>
<td>SD</td>
<td>3.7</td>
<td>1</td>
</tr>
<tr>
<td><strong>17. SDI development is linear, i.e. given specifically defined system’s setup it is possible to be sure about its behaviour. (Non-linearity)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
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<tr>
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<td>D</td>
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<td>11</td>
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<tr>
<td>SD</td>
<td>34.6</td>
<td>9</td>
</tr>
<tr>
<td><strong>18. Audits and evaluations (internal or/and external) help to improve SDI performance. (Feedback loop)</strong></td>
<td></td>
<td></td>
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<tr>
<td>SA</td>
<td>22.2</td>
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<tr>
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</tr>
<tr>
<td>SD</td>
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</tr>
<tr>
<td><strong>19. SDI can be described as a set of components working together for a particular purpose. (System)</strong></td>
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</tr>
<tr>
<td>SA</td>
<td>11.5</td>
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<tr>
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<tr>
<td>SD</td>
<td>3.8</td>
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<tr>
<td><strong>20. SDI actors behave according to strictly defined rules and procedures. (Complexity)</strong></td>
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<tr>
<td>SA</td>
<td>0.0</td>
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<td>D</td>
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<td>12</td>
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<tr>
<td>SD</td>
<td>14.8</td>
<td>4</td>
</tr>
<tr>
<td><strong>21. Bottom-up processes play an essential role in shaping SDI. (Self-organization)</strong></td>
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<tr>
<td>SA</td>
<td>25.9</td>
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<tr>
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</tr>
<tr>
<td>SD</td>
<td>0.0</td>
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</table>

SA, Strongly Agree; A, Agree; SD, Strongly Disagree; D, Disagree.

*The information in brackets was not included in the version of the questionnaire that was sent to the workshop participants.*
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An architectural style for spatial data infrastructures

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This work proposes an architectural style, a pattern, for spatial data infrastructures (SDIs). This style provides a tool and a shared vocabulary to help system architects to design these infrastructures, and facilitates the exchange of knowledge about them. This style is defined under the component-and-connector architectural viewtype, extending the client–server and shared-data styles. The style has been created after analyzing six of the most relevant SDIs and geo-service architectural proposals. Several architectural elements that these proposals have not properly addressed are considered. Three real projects, with published architectural views or models, have been examined to verify the applicability of the style. The proposed style offers a systematization and refinement of knowledge about SDIs, grounded in well-known concepts in software architecture.

Keywords: Spatial data infrastructure; Software architecture; Architectural style; Pattern

1. Introduction

The definitions of Spatial Data Infrastructure (SDIs) have included, directly or indirectly, the necessity to provide search, visualization and data download services (GSDI Technical Working Group and contributors 2004). Besides these services, and as anticipated by the USA Federal Geographic Data Committee (FGDC) Geospatial Applications and Interoperability Working Group (Evans 2003), SDIs have grown in complexity by including other types of services (Bernard and Craglia 2005). As SDIs become more complex, their software architecture becomes more relevant in order to facilitate their design and understanding. This paper is focused on the software architectural design of SDIs that are developed by single organizations.

There are several previous works which propose architectural models for SDIs. Most of these proposals have their technical roots in a work of the FGDC Geospatial Applications and Interoperability Working Group (Evans 2003), which describes a model of geospatial processing based on interoperable geospatial services. Among the most relevant SDI architectural models are the proposal by GeoConnections (2005) about the Canadian infrastructure and the initial proposals for the European SDI established by the AST Working Group (2002), though this initial European proposal is currently being superseded after the approval of the
INSPIRE directive: the first draft of the INSPIRE technical architecture has already been published (INSPIRE Drafting Teams ‘Data Specifications’, ‘Network Services’, ‘Metadata’ 2007). These architectural models provide high-level views of SDIs and, consequently, they lack some elements that would have been defined for a detailed software architecture: they are focused on the allowed components for the architecture but they barely mention, when they are mentioned, other elements of an architecture, as the types of relationships among the components, their visible properties or necessary constraints. There are also non-obvious overlaps among the different architectural models, e.g. components with different names but similar roles are common. Finally, they are not completely grounded in well-known architectural models: a Service Oriented Architecture (SOA) (Erl 2004) is commonly mentioned as the basis, but this architectural model fails to capture many components included in these models like applications or data repositories; no other references to software architectural models are provided.

Because of the lack of more detailed architectural models for SDIs, the high-level proposals cited in the previous paragraph have been used to support the development of many of such infrastructures. As these proposals do not follow any kind of common structure or pattern, comparing them, or verifying that a given information system actually follows one of the reference models they present, is difficult and ad hoc.

This paper provides an architectural style that unifies some of the most important SDI technical architectural proposals. Besides this, the style is a template that presents the concepts and rules needed to document the architecture of an SDI, either to design one, or to communicate this architecture to others.

The rest of this paper is structured as follows. First, some definitions are given about software architecture and the concepts of view, viewtype and style. Then an architectural style for SDIs is defined after analyzing the architectures proposed by six SDIs and geographic service reference models. In section 4, three real SDI projects with published architectural descriptions are studied to determine their compatibility with the proposed style. The next section offers an architectural description of one of these projects, following the proposed style, to highlight the benefits of its use. Section 6 discusses the methodology used in this paper. In the final section, some important issues are highlighted and conclusions are drawn.

2. Software architecture

Although there is not a single accepted definition, a software architecture can be defined as the structure of a system, and is formed by elements, sometimes called components, their properties and the relationships among them and possibly with their environment. This definition roughly summarizes the main points of those proposed by Kruchten et al. (2006), Clements et al. (2003) and the IEEE Architecture Working Group (2000).

The software architecture of a system is an inherent property of this system, but documenting this architecture may be a very complex task. The approach that has been consolidated over the past few years is expressing the software architecture of a system as a set of views, each of them addressing different concerns for different users. Indeed, documenting an architecture without specifying the type of view that is being used tends to create too complex diagrams, with too much information and without a clear separation of concerns.
2.1 Architectural views

The ‘views and beyond’ proposal by Clements et al. (2003) or the IEEE Architecture Working Group (2000) recommended practice for architectural description of software-intensive systems, share a similar approach that allows us to describe the architecture of a system as a set of views which follow some defined viewtypes, viewpoints in the IEEE standard, and styles.

A view is a representation, typically a graphical representation of some of the elements and relationships that are present in a system. For instance, a view of a given Web information system could be a diagram showing its Web services as boxes and the relationships between these services, e.g. requests and responses, as arrows.

A viewtype is a definition of the allowed element types and relationship types that can be used to describe a system from a certain perspective. For instance, a viewtype for Web information systems could indicate that only Web services, as boxes, and service chaining, as arrows between these boxes, should be included (and not databases, applications and other components of the system). This viewtype could be useful to have a perspective of the high-level processes, i.e. service chaining, that occur in that system.

A style is a specialization of a viewtype; it can specify that only certain elements and relationships from the viewtype are allowed, and include also other constraints. A style for standards-based Web information systems could specify that only certain types of Web Services, e.g. those suggested by a certain standardization organization, can be included.

The architecture of a system will be documented by a set of views of this system. These views will address different concerns and will be created following the guidelines provided by the viewtypes and styles provided by the literature. The ‘views and beyond’ methodology describes a set of viewtypes and styles, but it does not propose a fixed set of views for a given system: the architects will decide the views they need to completely document their system.

In the rest of this paper, the ‘views and beyond’ proposal is followed, and therefore the style presented here is under the umbrella of one of the viewtypes defined by Clements et al. (2003): the Component-and-Connector (C&C) viewtype, which is described in the next subsection.

2.2 The C&C viewtype

Clements et al. (2003, p. 103) indicate that C&C views include elements with runtime presence, such as clients or servers, which are the components, and the pathways for their interactions, such as information flows, captured as connectors. A general C&C viewtype thus consists of allowed component and connector types, constraints for allowed relationships (i.e. which connectors are attached to which components), some properties of the components and the connectors (e.g. a name or a type) and maybe also some topological constraints (e.g. ‘a connector must not be attached to another connector’).

3. An SDI style for the C&C viewtype

This section defines an SDI architectural style for the C&C viewtype. The objective behind the definition of this style is to capture, unify and systematize the previous knowledge on SDI architectural models, and to explicitly take into account elements
that are not typically considered in these models (i.e. constraints), or considered only implicitly (i.e. data stores).

A hybrid style is defined in Clements et al. (2003, p. 201) as the combination of two or more existing styles. From the styles for the C&C viewtype in this book, those that have been considered more appropriate as a basis for this work are Shared-Data and Client-Server. The proposal in this paper is a specialization of a hybrid style which combines these two:

(i) **Shared-Data**: this style highlights interactions dominated by the exchange of persistent data (i.e. data that are stored in a non-volatile storage, such as a hard disk, so it remains available between executions of the processes that make use of it). It is important for SDIs because spatial datasets and metadata are persistent and relevant data, shared by different kinds of services. In this style, there are two types of components: shared-data repositories and data accessors. The possible connector types are data reading and data writing. Data accessors are attached to data repositories by means of these types of connectors.

(ii) **Client-Server**: this style shows asymmetric interactions among components, from clients to servers. It is important in SDIs because they follow an SOA: some of their services will act as servers, for other services or for applications, and others will act as clients for other services, and these interactions are the base of developing complex functionality. In this style, there are also two types of components: clients, which request services, and servers, which provide them. The connector type is thus request/reply. Clients are attached to servers.

The next sections describe the elements of a new style for SDIs. These elements extend those in the Shared-Data and Client-Server styles to tailor them to the necessities of a software architect designing an SDI. This style has been designed from the experience of the authors in several SDI projects (Béjar et al. 2003, 2004, Latre et al. 2005, Portolés-Rodríguez et al. 2005), taking into consideration several of the most relevant SDI and geoservice architectural descriptions in the bibliography. A discussion about the relationship between the elements proposed here and those in the bibliography is also presented.

### 3.1 Previous work on SDI architectural models

These are the main bibliographic references that have been taken into consideration, and the reasons to choose them:

- The International Organization for Standardization (ISO) Technical Committee 211 (TC 211) standard on geographic information services (ISO 19119, ISO/TC 211 (2003)): this is the most thorough taxonomy of geoservices available. From a technological point of view it is an abstract specification, but most, if not all, current SDI initiatives are using Web services and this technology fits very well with the ISO standard.

- The OGC Web service architectural description (Whiteside 2005): the geoservice architecture from the most active standardization organization, with ISO, in the geospatial field. It is quite similar to the ISO standard, but it is technologically specific (Web services, based on Web protocols or SOAP, and XML to transfer data).

- The FGDC Geospatial Interoperability Reference Model (GIRM) (Evans 2003): the concept of national SDI was developed in the USA, and the FGDC
An architectural style for spatial data infrastructures

set up this guide, one of the first and most relevant for these kinds of infrastructures. Besides this, this model was included in the first position paper on architecture for the Infrastructure for Spatial Information in Europe (INSPIRE) (AST Working Group 2002).

(iii) The Canadian Geospatial Data Infrastructure Architectural Description (GeoConnections 2005): the architecture of one of the leading projects in national SDIs in the world.

(iv) The final text of the European Union Directive for the establishment of a European SDI (INSPIRE, European Parliament and The European Council (2007)): relevant because it establishes the minimum requisites for all national SDIs of the EU member states to be part of a European SDI. Although it could be considered that it does not define any architecture, the truth is that although there are not any diagrams, it gives some detail on the components that national SDIs in the EU must have, in some cases more deeply than other architectural proposals.

(v) A proposal from the European Commission (EU) Joint Research Center (JRC), presenting the initial steps leading to the establishment of the European Geographic Information Portal (Bernard et al. 2005). The JRC is the institution in charge of providing scientific and technical support of the EU policies, among them INSPIRE. Although, of course, this list may never be complete, a reference to the Global SDI (GSDI) could be expected. But the GSDI cookbook (GSDI Technical Working Group and contributors 2004) does not suggest an SDI architectural reference model; it refers to other documents for this (especially ISO and OGC standards) which have been considered.

3.2 Component types

The component types in this section are specializations of those in the client-server and shared-data styles defined in Clements et al. (2003). Regarding to this, although the ISO 19119 standard is platform-neutral, most other bibliography on SDIs and geoservices assumes an SOA, deployed over Internet protocols with XML as the data exchange format, i.e. Web Services (Booth et al. 2004); this is also the case of this work. The component types have been chosen because they play relevant roles in SDIs, but not all of them need to be present in every SDI. Their names have been selected from the bibliography when there seemed to be a high degree of consensus. When this has not been possible, they have been chosen to highlight their main characteristic. The intention has been to capture the main structure of an SDI, so the component hierarchy is not very deep. The ISO and the OGC have done a good work specifying types of geoservices, so in this paper only the higher levels in the component hierarchy, which hold a higher level of information about the structure of an SDI, have been defined.

Figure 1 shows the hierarchical relationships among these component types, and among those in the client-server and shared-data styles. This is a Unified Modeling Language (UML) class diagram where classes represent component types. Table 1 holds a comparison of these component types with those that appear in the considered bibliography. The table shows which of the proposed component types appear in the different architectures studied. It also indicates when they appear with a different name, with a similar, but not equal, meaning, or when they do not appear but are related, even indirectly, to other explicit elements. The definitions of the proposed component types are given in the next list.
Figure 1. Hierarchical relationships among SDI style component types.
Table 1. SDI style component types compared with those in the other architectures studied.

<table>
<thead>
<tr>
<th>Component Type</th>
<th>OGC</th>
<th>FGDC</th>
<th>GIRM</th>
<th>ISO 19119</th>
<th>INSPIRE</th>
<th>EU Geoportal</th>
<th>Canadian GDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Service</td>
<td>!/</td>
<td>√(G)</td>
<td>√(G)</td>
<td>√(G)</td>
<td>√(G)</td>
<td>√(GI Service)</td>
<td>√(Service)</td>
</tr>
<tr>
<td>SDI Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>√(G)</td>
<td>×(G)</td>
<td>√(GI Service)</td>
<td>×</td>
</tr>
<tr>
<td>Processing Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Transformation Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Information Management Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Portrayal Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Access Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Catalog Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Gazetteer Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Knowledge Model Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Application Service</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SDI Client</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Geoportal</td>
<td>!/</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×(G)</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>
Table 1. Continued.

<table>
<thead>
<tr>
<th>Component Type</th>
<th>OGC</th>
<th>FGDC GIRM</th>
<th>ISO 19119</th>
<th>INSPIRE</th>
<th>EU Geoportal</th>
<th>Canadian GDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>×</td>
<td>✓ (User application) ×</td>
<td>×</td>
<td>×</td>
<td>× (6)</td>
<td>✓</td>
</tr>
<tr>
<td>Metadata Repository</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
</tr>
<tr>
<td>Dataset Repository</td>
<td>× (7)</td>
<td>✓ (Content Repository)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
</tr>
<tr>
<td>Spatial Dataset</td>
<td>× (7)</td>
<td>✓ (Feature and Coverage Repositories)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
</tr>
<tr>
<td>Knowledge Model</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>× (7)</td>
<td>×</td>
</tr>
<tr>
<td>Repository</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

×: This architecture does not include explicitly this component type.  
✓: This architecture includes this component type with similar semantics, though maybe with a different name (it is given within parentheses).  
(1) There is also a Registry Service in the ISO 19119 standard, but with a different meaning.  
(2) Not mentioned explicitly in the INSPIRE directive, but an indirect reference seems implied when it indicates that the discovery services will support search by geographical locations.  
(3) The ISO 19119 registry service provides access to metadata about types, so it could be considered as a specialization of the knowledge model service.  
(4) The FGDC GIRM mentions clients in its interoperability stack, indicating that user applications will act as clients in the distributed system they propose.  
(5) OGC defines Web portal services, but they are application services as defined in this work.  
(6) The geoportal is defined in this work as an application that aggregates instances of GI services, but application is not defined and not mentioned any more.  
(7) Not explicit components, but they are indirectly taken into consideration (i.e. considering [some of] the contents of the store type).  
(8) The architecture does not reference it, but a geospatial ontology server, a specialization of the knowledge model service, has been created for this SDI (M3GO, http://intelegeomatics.com/ogm3/).  
(9) A thesaurus service as defined for the EU Geoportal could be considered as a specialization of a knowledge model service.  
(10) The catalog in the OGC architecture can store metadata and datasets which can be schemas, models, semantic documents, etc., so it could play the role of the knowledge model service.
• **Web Service**: all kinds of Web services (Booth et al. 2004).

• **SDI Service**: all web services in an SDI will be a specialization of an SDI Service. The name has been chosen to reinforce the idea behind the architectural style while avoiding other names than could be understood as too restrictive (i.e. calling them geographic information services or geoservices seems to imply that they all access geographic data, and this will not be the case for some of them).

• **Processing Service**: these services are designed to make generic processing of data, typically spatial data. These data can be provided when calling their operations or the services can access to some data repositories.

• **Transformation Service**: services that allow spatial datasets to be transformed with a view to achieving interoperability.

• **Information Management Service**: they store and provide access to data and metadata.

• **Portrayal Service**: they support the visualization of spatial datasets.

• **Access Service**: these services allow downloading or accessing spatial datasets or parts of them.

• **Catalog Service**: these services make it possible to discover, explore and evaluate datasets, services, etc. by means of the metadata describing them.

• **Gazetteer Service**: they offer geocoding functionalities, which link toponyms and their spatial locations.

• **Knowledge Model Service**: they offer discovery and access to shared knowledge models in order to facilitate the semantic interoperability among different services, applications, etc.

• **Application Service**: those used to support client applications, especially thin, i.e. Web, clients.

• **SDI Client**: software that gives human users access to the services in an SDI.

• **Application**: a kind of computer software that allows users to perform a set of tasks, most of them using SDI Services.

• **Geoportal**: web sites mainly focused on geographic content, geographic services, and the tools to discover them. Although it would be possible to model a Geoportal as a type of application, the relevance of Geoportals for SDIs in the bibliography supports considering them on their own.

• **Metadata Repository**: a repository which holds identifiable metadata and structured data about other resources in the SDI (datasets, services, etc).

• **Knowledge Model Repository**: a repository which holds knowledge models, defining knowledge models as data models, schemas, ontologies, thesauri or any other explicit conceptualization of knowledge in a domain.

• **Dataset Repository**: a repository that holds datasets, defining datasets as identifiable collections of data.

• **Spatial Dataset Repository**: a repository that holds spatial datasets, which are defined as identifiable collections of spatial data (i.e. data with a direct or indirect reference to a specific location).

### 3.3 Connector types

In the bibliographic references on SDI and geoservice architecture listed before, there is little attention paid to connectors. At most there are some indications about what kinds of components can connect to others without further details. This could
be due to the fact that defining special connector types seems not necessary for SDIs; but since connectors in general are barely mentioned, it could also be possible that they have not been considered at all. After a more detailed study, neither new relevant types of connectors nor refinements of those provided by the Client-Server and Shared-Data styles have been found. Therefore, these are those included in the SDI style:

- **From the Client-Server style:**
  - **Request/Reply**: the invocation of a server by a client and its response go through this connector type. In the SDI style, SDI Clients (i.e. Applications) or SDI Services can make requests to SDI Services, and the latter can reply to the former.

- **From the Shared-Data style:**
  - **Data Reading**: data accessors read data from data repositories. In the SDI style, different types of SDI Services can read data (i.e. Information Management Services).
  - **Data Writing**: data accessors write data to data repositories. In the SDI style, different types of SDI Services can read data (i.e. Access Services).

### 3.4 Properties

As with the connector types (see Section 3.3), it has not been possible to find relevant properties for SDIs that were present in a significant number of architectural proposals, but missing in the generic C&C styles (Client-Server and Shared-Data). But among the several properties for these styles suggested by Clements et al. (2003), there are some that are used in some studied SDI architectures:

- **Name**: for components and connectors, suggesting their functionality or the nature of its interactions.
- **Type**: the type which components and connectors belong to.
- **Types of data stored**: for **Shared Data Repositories**.

This list of properties is not closed. System architects may consider it useful adding others when designing their SDIs following the proposed style. For example, properties indicating access permissions or performance indicators could be useful. They just seem a little too specific for the objectives of this work.

### 3.5 Constraints

As defined before, constraints in an architectural style are rules which specify how the elements defined for the style, especially components and connectors, can be used, and the valid interactions among them. This section defines some fundamental topological constraints, which are those that define how components relate to each other by means of connectors.

First of all, these are the allowed connector configurations (topological constraints) defined for the Client-Server and Shared-Data styles (they have already been mentioned when describing the Connector Types):

- **From the Client-Server style:**
  - **Client Requests** from Server.
  - **Server Replies** to Client.
• From the Shared-Data style:
  • Data Accessor **Reads Data** from Shared-Data Repository.
  • Data Accessor **Writes Data** to Shared-Data Repository.

In the studied SDI and geoservice architectures and models, there are not many clear references to constraints. Nevertheless some can be found:

• **OGC**: this architecture describes some ideas which are constraints indeed. They would be clearer if they were separated and made explicit. The constraints designed for the style in this paper are compatible with these ideas.

• Services are organized into tiers but loosely, and it is not required to separate services that way. Services can use other services within the same tier or not.

• All kinds of services may access data, although most of data will be accessed by Information Management Services.

• **FGDC GIRM**: this model organizes its components in an ‘interoperability stack’. In this stack, user applications have access to services and to content repositories (direct data access), and services access other services and content repositories. In our proposal, **Clients** are not **Data Accessors**, so they are not allowed to read or write to **Shared Data Repositories**; this is more restrictive than the GIRM proposal, where applications can directly access content repositories. As most other SDI proposals separating clients from data by means of services, this constraint has been included in the style designed in this paper.

• **ISO 19119**: in this standard, the engineering viewpoint section establishes as a reference model of a four-tier logical architecture. This logical architecture is then mapped to different physical ones, establishing thus some constraints on the topology of interactions among services. The problem is that this architecture is designed for generic Information Technology (IT) services as well as for GIS-extended services, so it is a general proposal with a broad scope. If besides this we consider that this standard is not for SDIs but for geoservices in general, it results that the level of detail is not appropriate to extract conclusions useful for an SDI style as the one defined in this work.

When defining the SDI style, new component types have been pointed out. These component types extend those in the Client-Server and Shared-Data styles, so they inherit their constraints too. But not every component type extending Data Accessor should be allowed to read *and* write from/to any kind of Shared-Data Repository. New constraints are needed to explicitly capture these new rules. These constraints are given as forbidden topological connections among some component types:

• **Portrayal Service**:
  • **NOT Writes to** Shared Data Repository.
  • **NOT Reads from** Knowledge Model Repository, Metadata Repository.

• **Access Service**:
  • **NOT Reads from AND NOT Writes to** Knowledge Model Repository, Metadata Repository.

• **Catalog Service**:
  • **NOT Reads from AND NOT Writes to** Knowledge Model Repository, Dataset Repository.

• **Gazetteer Service**:
  • **NOT Reads from AND NOT Writes to** Knowledge Model Repository, Metadata Repository.
Knowledge Model Service:
  - **NOT Reads from AND NOT Writes to** Metadata Repository, Dataset Repository.

These constraints intend to separate the roles of the different service types. For example, a Portrayal Service is specifically designed to portray existent spatial datasets, so, although it is basic to allow it to read Spatial Dataset Repositories, it is not allowed to modify them or to read from other types of repositories. If one of these services would be needed to read a knowledge model or some metadata, and this situation is perfectly possible, it should do it through a specialized service (a Knowledge Model Service or a Catalog). This is in order to follow good design principles, like a clean and strict separation of service roles. But in some situations, these constraints may be unnecessarily complex: for example, one could want to create a Catalog Service able to read just some data from a Spatial Dataset Repository, but without the burden of setting up an Access Service. This can be done by defining a new component type which extends Catalog Service and Access Service. This component would be thus allowed to read from a metadata repository and from a dataset repository. The idea behind constraining the data repositories which can be accessed from different components is to help to clarify their function; but a system architect may decide that for a specific SDI a catalog component which accesses metadata and datasets is the best solution. This style allows for that while making it explicit that this component is a Catalog Service and an Access Service. Making it explicit is useful because it gives roles and precise meanings to the elements in an SDI, and because it helps this system architect to document the design, relating this component to the component types defined for this style. This also makes the design easier to understand to other system architects who know the SDI style.

It is also important to notice that geoportals and Applications are not allowed to access Shared Data Repositories, because they are not Data Accessors. If this necessity arises in the process of designing an SDI, it is a clear indication that some Application Services are needed. This is one of the reasons why Application Services have been defined: to separate Applications from the Dataset Repositories, helping to enforce the usual rules of layered IT systems.

A final consideration is that Portrayal Services have been allowed to read from Dataset Repositories. It could be argued that this would be the role of an Access Service and that most Portrayal Services in SDIs would also have to be Access Services. This decision has been taken precisely because the main function of Portrayal Services is reading Spatial Datasets and portraying them. If their main function includes reading Datasets, it seems correct to allow them to read from Dataset Repositories.

As in the case of property types (Section 3.4), this list of constraints is not closed. They have been chosen because they capture the basic ideas which appear, normally in an implicit manner, in the SDIs studied, and have proven themselves to be useful in the experience of the authors with SDI projects.

4. **Analysis of real SDI architectures**

In this section, three different projects are analyzed in order to determine if real SDIs have architectures that fit the proposed style. These projects are from regions in three different European countries and have been developed by different people with different technologies, objectives and constraints. They have been chosen...
because they give enough public architectural information, claim to be following SDI principles and have a view that is close to the C&C viewtype.

4.1 Architecture of the Galicia CMA SDI

Galicia is a Spanish Region, NUTS-2 in the EU terminology, located at the northwest corner of the Iberian Peninsula. The climate is warm and wet so its land is covered with many forests (69% of its surface). This fact makes forests the main concern of their environmental department (Consellería de Medio Ambiente, CMA) which is responsible for water use, disposal of waste and protected natural environments as well. This department had found the same kinds of problems with geographic information that SDIs address: incompatible data formats and information systems, difficulties in disseminating data among their users (it is a very decentralized department), difficulties in finding relevant information, etc. The solution adopted in 2001 to overcome these problems was to develop a geographic information system for this department, but following INSPIRE principles and recommendations in architecture and standards, thus effectively building an SDI. This project had to be developed using the available commercial software licenses in the CMA in a COTS (commercial off-the-shelf) approach. This infrastructure was designed to become the core of a future Galician SDI, and it is described in some detail in Béjar et al. (2003). In this paper, there is an architectural view of this SDI, referred to as a ‘Service Oriented Architecture’, which is shown in figure 2.

This architecture is depicted in a layered way, focusing on its components and some of their properties. It must be noted that there are neither explicit connectors nor constraints in this diagram, but some of them are detailed in the text of the paper. Regarding the components, and following their function as explained in the paper, they all can be matched to some of the component types proposed in the SDI style:

- In the layer ‘Data and Metadata Sources’:
  - Vector Data and Raster Data are Spatial Dataset Repositories.
  - SDI Documentation is a Shared Data Repository.
  - Metadata is a Metadata Repository.

- In the layer ‘Chainable Services’:
  - WMS-Core, WMS-Raster Core and WMS-Environmental are Portrayal Services.
  - WFS-Core, WFS-Environmental and WCS-Raster are Access Services.
  - OGC Metadata Catalog and OGC Services Catalog are Catalog Services.

- In the layer ‘Integration Services’:
  - Access Control is a specialized Application Service.

- In the layer ‘User Applications’:
  - All components in this layer are Applications.

Some connectors and constraints can be extracted. At least there is one that is quite clear and that also matches the proposed style:

- ‘User applications are built on top of distributed services’ (p. 94, emphasis added). This implies a connector between user applications and distributed services and follows two of the defined constraints:
  - Clients Request from Servers. Applications in the SDI style are Clients and the SDI Services are Servers, so Applications Request from the SDI Services, as it happens in the CMA SDI architecture.
Data Accessor \textit{Reads and Writes Data} from Shared-Data Repository. These constraints imply that any component type that is not a Data Accessor cannot read or write data from Shared-Data Repositories. Neither Applications in the SDI style nor ‘User Applications’ in the CMA SDI architecture are Data Accessors. The reason is that they access ‘Services’ instead of ‘Data Sources’.

Finally, it is worth noting that in this architecture every component has the properties suggested for the SDI style (name, type and types of data stored for repositories), but the connectors do not have any.

\section*{4.2 Architecture of the Piedmont local SDI}

The SITAD is the name of a project which points towards the creation of a local SDI in the Piedmont region, Italy. Designed according to INSPIRE principles, it
aims at facilitating the coordination of public sector organizations to collect, manage, distribute and reuse spatial data (Cipriano and Garretti 2004). This paper describes the components in the SITAD and provides the architectural diagram shown in figure 3. Although it is not indicated whether this diagram follows any existing architectural view type, it is stated that it ‘represents the presentation logic, the business logic and the data logic of the infrastructure’ (p. 4). According to the architectural principles in Clements et al. (2003), all that information should probably have been distributed among several views (i.e. in the same diagram are shown elements quite different like Web servers (software components) and metadata records (datasets)). Anyway, the information in this diagram and the text of the paper enable the evaluation of some elements in the SITAD architecture. These are the components described in the paper mapped, as far as it has been possible, to their equivalent types proposed in the SDI style:

- Application to compile metadata is an Application.
- Metadata catalogue (MTD in the figure) is a Catalog Service.
- Unique catalogue gateway is a Geoportal.
- Web map services are Portrayal Services.
- Download services are Access Services or Information Management Services if they hold non-spatial data.

Figure 3. Architecture of SITAD infrastructure (taken from Cipriano and Garretti (2004, p. 5).
Visualization services are **Information Management Services** if they show non-spatial data.

- Multi-map service viewer is an **Application**.
- User interfaces (i1 and i2 in figure 3) are **Applications**.
- DBs (from the figure) are **Dataset Repositories**. When they have the ‘Spatial Box’ over them, they are **Spatial Dataset Repositories**.

With regard to connectors or constraints, there is little information that can be extracted from the paper. The text mentions that data are accessed via on-line services and served to clients, which points out that there must be connectors between data and services (at least **Data Reading**) and between services and clients (**Request/Reply**). Probably this also implies several of the constraints defined for the SDI style, though trying to specify this would be pure speculation. There are also some connectors portrayed in figure 3, which seems to confirm this interpretation of the text.

The only property that is shown for some components is their **type**. There are not any properties for the connectors.

### 4.3 **Architecture of the North Rhine-Westphalia GDI**

As described by Brox *et al.* (2002), the Geospatial Data Infrastructure North Rhine-Westphalia (GDI-NRW) is an initiative of the Land North Rhine-Westphalia, in Germany. It started in January 2000, with the objective to develop a market for geographic information in that Land by connecting users, service providers and enablers, integrators, data producers and infrastructure providers. In addition to a general description of the objectives of this SDI, this paper includes an architectural model with a taxonomy of services and technical components (pp. 31–33). The component diagram is shown in figure 4. Although this diagram presents an architectural model without any architectural view, it does not make it a less valid or

![Figure 4. GDI North Rhine-Westphalia component diagram (taken from Brox *et al.* (2002, p. 32).](image)
relevant reference for the purpose of verifying the applicability of the SDI style in real projects.

First of all, instead of defining a taxonomy of services, the GDI-NRW service taxonomy adheres to the one described by ISO/TC 211 on geographic information services (ISO/TC 211 2003). Then, focusing on the technical components, they define a model based on Web services, with a number of components which support them. These geospatial services are classified into three categories:

- GDI-NRW Search and Discovery Services: organization, discovery and access of geospatial information.
- GDI-NRW Access and Retrieval Services: access to geospatial information outside the scope of the catalog services.
- GDI-NRW Web Mapping Services: distributed Web mapping.

The components described in figure 4, following OGC specifications, fall into these categories:

- Catalog Server: search and discovery of geospatial data and services through its metadata.
- Web Map Server: services for distributed Web mapping.
- Web Coverage Server: services for access to coverage data.
- Web Feature server: service for access to feature data.

The other component types in the figure are the clients, which access any kind of data distributed in the GDI-NRW through the services, and the metadata and geospatial data storages, which are not defined though some comments are given regarding their contents.

The paper ends giving some future steps to the architectural model, which include (with little detail) services for portrayal and presentation, ordering and payment, security, authentication, gazetteers and an e-commerce framework.

Regarding the component types in figure 4, and understanding their function as explained in the paper, they all can match the component types of the SDI style:

- GDI Client is an SDI Client.
- Catalog server is a Catalog Service.
- Web Feature Server and Web Coverage Server are Access Services.
- Web Map Server is a Portrayal Service.
- Metadata Storage is a Metadata Repository.
- Geospatial Data Storage is a Spatial Dataset Repository.

The proposed services for the evolution of the architectural model can match those in the SDI style, though there are some aspects that need to be clarified:

- Portrayal and Presentation Services are Portrayal Services.
- Gazetteer is a Gazetteer Service.
- Ordering and Payment Services are SDI Services. These kinds of services are quite specific and important and it could be argued that they should have been included in the style. The problem is that we are far from a consensus on the e-commerce technical aspects of an SDI. Although this issue is important, and addressed in some high level SDI specifications and regulations (i.e. in the INSPIRE directive text), the idea behind the proposed style is to capture, refine and systematize the existing knowledge about SDI architecture. The e-commerce issue has not been defined or implemented to an extent that makes
this viable. On the other hand, the SDI style does not prevent an SDI architecture from having e-commerce services, which would extend the SDI Service type, and maybe others (i.e. Access Services).

- Security and Authentication Services are SDI Services. With these kinds of services arises a problem that is very similar to the one discussed in the previous point.

From the text of the paper and figure 4, some connector types and constraints can be extracted for the GDI-NRW. There are five kinds of relationships in the figure:

(i) GDI client uses Catalog Server, Web Feature Server, Web Coverage Server and Web Map Server: this one is called a Request/Reply connector in the SDI style.

(ii) Web Feature Server and Web Coverage Server get data from Geospatial Data Storage: this one would be equivalent to the Reads Data connector.

(iii) Web Map Server displays data from Geospatial Data Storage: this is also equivalent to Reads Data. The paper does not give any indication of the difference between this connector and the get data from discussed before.

(iv) Catalog Server discovers Metadata Storage: there are no explanations about this connector, but most probably it does not mean that the Catalog Server needs to discover the location of the metadata it serves! Indeed, it seems that this connector is similar, if not identical, to the gets data from in the diagram, so equivalent to Reads Data.

There is another connector in the figure, which helps to illustrate the problems of creating an architectural diagram without defining its view type: the Metadata Storage describes Geospatial Data Storage connector. If the diagram is a style of a viewtype similar to the C&C, which seems implied in the paper, then the connectors should be among components, not among other elements. Although the depicted type of connector is undoubtedly present (i.e. some metadata in the Metadata Storage will surely describe some data in the Geospatial Data Storage), it is clearly different from the others, because it does not show a connection between components: probably it would be better placed on another diagram with a different view type.

With regard to constraints, the diagram shows a layered architecture with connectors that seem to enforce some of the constraints defined for the SDI style: clients in the GDI-NRW component diagram only use servers (Client Requests from Server), and only the servers are allowed to get data or metadata from the storages. Therefore, it could be assumed that because servers in this diagram are all Data Accessors and storages are all Shared Data Repositories, the constraint Data Accessor Reads Data from Shared-Data Repository is implicit.

The only property that is shown both for the components and the connectors is their type. Since this proposal is an architectural model instead of an actual architecture, and it includes component types instead of components, this is the only property that makes clear sense.

5. Application of the SDI style

This work would not be complete without an example of application of the proposed style to document a view of an SDI architecture. Thoroughly documenting the views of a software architecture is a complex task (see Clements et al. 2003, pp. 317–322 for some guidelines) far from the intention of this paper; this section is focused on the primary presentation, as defined in that book. There are many
different options to document views, from formal architectural description languages (ADLs) to various graphical notations. UML has been chosen because it is widely extended in the information systems community in general, and in the geospatial and SDI community in particular. As UML can be used in different ways to document an architectural view, some clarification is needed: objects will represent the different components in the view and associations among them will represent the connectors; different shapes have been used for the different types of objects (UML graphical stereotypes). Topological constraints are implied in the diagram (i.e. component types that must not be connected will not be connected).

The Galicia CMA SDI has been chosen as the example to avoid defining a new project environment. Since this architecture has been found to extend some of the component types in the SDI style, figure 5 has been included to facilitate the understanding of the architectural view that comes next. In that figure, classes represent component types, and those on top are the component types defined for the SDI style. In the rest of this section, this question will thus be answered: if the SDI style had been followed, how would a view of the Galicia CMA SDI architecture have been documented?

5.1 Galicia CMA architectural view following the SDI style

Figure 6 shows an architectural view of the Galicia CMA SDI, following the guidelines given by the SDI style. Several components projected, but not implemented, have not been included in order to have a diagram easier to understand. All the elements shown have their type: components have names and belong to a type defined in the SDI style, or belong to a type which extends one in the SDI style. Repositories include the data types they hold (one of their properties). Connectors are explicit: they have a name and their shapes indicate their type. The question is: what are the differences between this diagram and the one shown in figure 2?

![Diagram of Galicia CMA architectural view following the SDI style]

Figure 5. Galicia CMA SDI component types which extend those in the SDI style.
The first difference is that once the SDI style is known, the meaning of this diagram is better defined. Most component and connector types, except for those defined specifically for the project, have a defined meaning. Even from those that are not defined in the SDI style, i.e. the Web Map Service, things can be immediately deduced: for example, as the Web Map Service extends the Portrayal Service, everything that is true for the Portrayal Service (definition, constraints, etc.) must also be true for the Web Map Service.

This diagram is also more complete: connectors and also the types of the components are explicit. For example, it is now clear that the services do not write to the repositories, but only read from them.

Finally, as constraints are explicit for the SDI style, it can be sure that they are fulfilled: for example, it is clear that the applications in the Galicia CMA SDI do not read data from the data repositories (this was not so clear before).

6. Methodology discussion

In this section, the methodology that led to the results presented in this paper and the rationale behind the decisions taken are explained. The objective was to facilitate the architectural description of the distributed information systems that support SDIs, i.e. their technological backbone. This was divided into two tasks: analyzing the current technological proposals for SDIs, and presenting a unified model over solid software architectural concepts.

The bibliography was analyzed in order to find the most relevant sources of information about SDI technical architectures and their components. After selecting...
some of the fundamental documents, they were studied and crossed to find the common elements and the main differences. Table 1 summarizes most of the information that was gathered.

After the analysis of the bibliography, the knowledge collected and unified had to be presented in a way that made it useful to describe software architectures. The ‘views and beyond’ methodology was chosen to provide the architectural support of this work. Architectural styles are the mechanism provided by this methodology to describe the architecture of a particular class of systems, so the creation of a new style for SDIs was decided.

Clements et al. (2003, chapter 6.5) propose several options to create new styles. The option chosen was to combine two existing styles and to specialize from this combination. Combining two existing styles, the client-server and the shared-data styles, gave us roots in fundamental software architectural concepts. The specialization made was domain-specific. This allowed us to present the information about SDI technology collected and unified in the previous phase under the terms of a solid software architectural documentation methodology. The resulting SDI style is presented in Section 3.

Finally, the bibliography was analyzed again to find examples of systems that claimed to be SDIs in order to verify if their architectures could have been described with the SDI style. This was made in order to test the applicability of the style to real systems.

The choice of the ‘views and beyond’ methodology is justified because of its flexibility: the set of viewtypes and styles it provides is extensible, and the methodology itself gives guidelines to extend it. This has allowed us to present a result that fits a tried and proven software architectural methodology, while being able to incorporate domain-specific concepts, i.e. spatial concepts.

The ISO and International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Reference Model for Open Distributed Processing (RM-ODP), for example (Putman 2000), is an architectural methodology cited in some OGC documents, e.g. Whiteside (2005), so it could seem suitable to support our work. There were two reasons not to choose this option: firstly, this methodology prescribes a fixed set of views and it does not provide an extension mechanism similar to the one used in our work; and secondly, the RM-ODP is designed to specify architectures, not to describe them. Specifying is a task that goes beyond description and was out of the objectives of our work (there are discussions about the differences between description and specification in Putman (2000, p. 32) and Clements et al. (2003, p. 8)).

7. Conclusions

This work proposes a pattern to design and document distributed geographic information systems following SDI design principles. The pattern has been presented as an architectural style, defined under the component-and-connector view type, extending two well-known styles in distributed information systems: the client-server and shared-data styles. The style has been created analyzing several important SDI architecture proposals, finding their common elements, and giving them a unique name and a definition. Several elements that a software architecture should consider, which had not been addressed in these proposals yet, have also been discussed and included in the style (especially connectors and constraints). Three real SDI projects, with published architectural views or models, have been
examined to verify whether the style would have been applicable to them. For one of these projects, the style has been effectively applied to show how this could have been done.

The proposed style offers a systematization, refinement and extension of knowledge about SDI architectures. The style intends to facilitate the software creation and integration activities in SDI development, so its usefulness is independent of the SDI scope (local, regional, national, etc.). Anyone designing or communicating the architecture of an SDI may benefit from the guidelines provided by the style. The papers cited in Sections 4.1, 4.2 and 4.3 are good examples of the current necessity to communicate information about SDI architectures. The style may facilitate this communication, because it names, defines and arranges the basic common elements in SDI architectures, providing thus a common ground for understanding.

The style has been defined with its extension in mind: it is a minimum core of elements that are common to most SDI proposals, either explicitly or implicitly, but a system architect may extend it to address specific necessities of an SDI. Indeed, there are several aspects of SDIs that the style does not address: e-commerce, security, etc. These are issues which are currently under discussion, so it was considered that it was too early to include them.

There is a refinement of the SDI style that could have been considered: the use of OGC and ISO specifications for the components in the style when possible (i.e. instead of a Portrayal Service, a Web Map Service could have been included). Although this was seriously considered, a more abstract approach was decided. This decision was adopted to promote concepts before technologies and because the value of a style is larger when it can be applied to more architectures; specifying too much detail reduces its applicability. The result is a style that can be easily refined to allow only for OGC components but does not force them. In addition to this, neither ISO nor OGC has defined every component type in the SDI style, and almost none of the other elements (connectors, properties and constraints), so the style could not have been completely defined in OGC or ISO terms.

To finish these conclusions, it is important to remark two issues about the scope of this work. First of all, the style proposed refines the component-and-connector view type, but there are other view types and styles for software systems that would be interesting for SDIs. The second issue is that as well as being distributed geographic information systems, SDIs are also Information Infrastructures, composed by different independent systems working together. From this point of view, their architecture could not be designed, but ‘cultivated’ (Georgiadou 2006). This will require further advances that allow us to analyze their architectural properties not only in terms of their components, but also in terms of the systems that compose them.

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Towards Spatial Data Infrastructures in the Clouds

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Abstract. Cloud Computing is one of the latest hypes in the mainstream IT world. In this context, Spatial Data Infrastructures (SDIs) have not been considered yet. This paper reviews this novel technology and identifies the paradigm behind it with regard to SDIs. Concepts of SDIs are analyzed in respect to common gaps which can be solved by Cloud Computing technologies. A real world use case will be presented, which benefits largely from Cloud Computing as a proof-of-concept demonstration. This use case shows that SDI components can be integrated into the cloud as value-added services. Thereby SDI components are shifted from a Software as a Service cloud layer to the Platform as a Service cloud layer, which can be regarded as a future direction for SDIs to enable geospatial cloud interoperability.

1 Introduction

Cloud Computing is one of the latest trends in the mainstream IT world (Gartner 2009a). A cloud metaphor is used to represent large networking and computational infrastructures. From a provider perspective, the key aspect of the cloud is the ability to dynamically scale and provide computational and storage capacities over the internet. From a client perspective, the key aspect of a cloud is the ability to access the cloud facilities on-demand in a cost efficient way without managing the underlying infrastructure and dealing with the related investments and maintenance costs.
In this regard, Spatial Data Infrastructures (SDIs) undergo a transition from providing geodata towards providing web-based geoinformation (GI) (Kiehle 2007, Schaeffer et al. 2009). To provide this web-based geoinformation, massive processing tasks are required in a cost efficient way to maintain sustainability. In the past, the processing of geodata has been performed mostly on desktop machines and mainframes. Due to this requirement for massive processing capabilities, Cloud Computing is a promising approach. Additionally, this novel technology is beneficial to sufficiently scale these processing tasks on the organization's infrastructure or within an SDI. The problem of scaling can be demonstrated for the example in disaster management scenarios, which requires a large-scale computational infrastructure for extensive computations only for a short period of time. Another aspect related to scaling is the coupling of SDIs with the mass market domain such as the integration of volunteered geoinformation (i.e. collected via mobile phones) in SDIs. In this case many users create and share their geodata on-demand concurrently, which is seen as a beneficial application for SDIs to enrich existing databases in real-time. The risk management scenario as well as the volunteered geoinformation do not follow a fixed schedule (such as for instance the periodically update of data in an agency) and therefore require new approaches to technically meet the requirements and to limit the infrastructure costs. Therefore, Cloud Computing is a technical and economic opportunity for SDIs to support future geospatial applications. Moreover, it is also an approach for novel business to create, operate and utilize SDIs. All these aspects motivate to investigate the potentials of Cloud Computing for SDIs.

Thus, this paper presents a cloud-enabled SDI addressing some of the current obstacles of SDI development. Section 2 reviews the related concepts of Cloud Computing and SDIs. The cloud-enabled SDI is described in Section 3. The application of the risk management use case is presented in Section 4. In addition, Section 5 validates the scalability promise of the cloud computing paradigm with regard to the presented use case. Finally, Section 6 gives an outlook and concludes the findings.

2 Review of Relevant Concepts

This section provides a review of relevant concepts in the context of Cloud Computing and SDIs.

2.1 Cloud Computing

Cloud Computing is one of the latest trends in the mainstream IT world (Gartner 2008) (Gartner 2009a). Several IT companies such as Amazon,
Google, Microsoft and Salesforce have already built up significant effort in this direction (see Section 2.3.1). The term Cloud Computing describes an approach in which the storage and computational facilities are no longer located on single computers, but distributed over remote resources facilities operated by third party providers (Foster 2008).

Cloud Computing overlaps with some concepts of Distributed Computing and Grid Computing (Hartig, 2008). Both, grid and cloud environments provide a network infrastructure for scaling applications by sufficient storage and computational capabilities. However, Grid Computing is applied by the scientific community for large-scale computations (e.g. a global climate change model or the aerodynamic design of engine components). Whereas Cloud Computing enables small and medium-sized companies to deploy their web-based applications in an instant scaleable fashion without the need to invest in large computational infrastructures for storing large amounts of data and/or performing complex processes (Myerson 2008). As a consequence, national and international grid infrastructures (for example the Worldwide LHC Computing Grid\(^1\)) are typically funded by the government and operated by international joint research projects, whereas cloud infrastructures are operated by large-sized enterprises under economic aspects, such as Amazon or Google, enabling smaller companies to use their infrastructure (e.g. WeoGeo).

In essence, Cloud Computing is not a completely new concept, it moreover collects a family of well known and established methods and technologies under the umbrella of the term Cloud Computing. These well known methods and technologies are for example Software as a Service (SaaS) as a model for software deployment and virtualization as an efficient hosting platform (Sun Microsystems Inc. 2009). Besides, it describes a paradigm of outsourcing applications and specific tasks to a scalable infrastructure and therefore consequently enabling new business models with less up-front investments.

The following sub-sections describe the paradigm of Cloud Computing grouped by its characteristics and anatomy.

### 2.1.1 Characteristics

The key characteristics of Cloud Computing are the ability to scale and provide computational power and storage dynamically in a cost efficient and secure way over the web (ANSI 2009). Besides, a client application is able to use these resources without having to manage the underlying complexity of the technology. These characteristics lead to the following benefits:

- **Efficiency**
  
  From a provider perspective, Cloud Computing enables IT companies to

\(^1\) http://lcg.web.cern.ch/LCG/
increase utilization rates of their existing hardware significantly. Existing infrastructures such as large data centers are now able to utilize their hardware infrastructures more efficiently by dynamically distribute their applications and processes to free available resources in an on-demand fashion. From a client perspective, the client's infrastructure can be utilized to the maximum and whenever more resources are needed, additional resources could be provided by the cloud.

- **Outtasking**
  By outtasking software and data to computational facilities operated by third parties, clients do not need to operate their own large-scale computational infrastructure anymore. Therefore, enterprises of any size - from Web 2.0 start-up companies to global enterprises - can decrease their costs for initial infrastructure and maintenance significantly. Thereby, fixed costs can be transformed into variable costs and create a business advantage. This allows companies to rather focus on their business model than to maintain and invest in the infrastructure (software licenses & hardware).

- **Scalability**
  Cloud Computing resources (i.e. storage or computational power) are allocated in real-time and cloud resources scale the deployed applications automatically on-demand (for example in case of high amounts of requests). This allows cloud users to handle peak loads very efficiently without managing their own infrastructures. For example, load-balancing or developing highly available solutions for their software do not need to be regarded by the cloud users because such solutions are incorporated in the cloud implicitly. By deploying applications and data in the cloud, clients are automatically able to scale up their computational capacities (for example from a few to hundreds of servers) in an instant and on-demand fashion.

- **On-demand**
  Allocating cloud resources on a real-time and on-demand basis helps enterprises to utilize large IT resources instantly and efficiently (see the aspect of efficiency). In contrast to classical long term outsourcing contracts, on-demand usage with pay-per-use revenue models enable cloud users to restructure existing business processes or even to realize the novel business models with little investment (Gartner 2009b). The total cost of ownership (including initial investment in hardware, software licenses, energy, fail-safety and technical engineers) of self-hosted data centers is in contrast to a Cloud Computing approach which minimizes start-up costs and helps enterprises to put new promising business models into the market.
An additional characteristic of Cloud Computing is the support of Service Level Agreements (SLA) defining different service quality guarantees (for example hotline support, web service mean up time or a specific numbers of accessible CPUs) and contractual penalty clauses. Such contracts are of general importance for cost-performance ratio transparency in SOA governance and therefore an essential characteristic for potential future geospatial business models with defined value propositions.

There are still a number of open issues for Cloud Computing. One open issue is the existing barriers of adopting Cloud Computing aspects in existing IT infrastructures, which is exemplified in the so-called "Open Cloud Manifesto". Especially the absence of cloud interoperability due to vendor specific cloud APIs can be seen as one major obstacle. These specific APIs bind the applications of the cloud users to specific cloud vendors and therefore complicate the migration of applications between different cloud vendors (i.e. vendor lock-in). Standards are needed and will be addressed by the Open Cloud Consortium.

Besides data backup and recovery responsibilities the outsourcing of confidential data from data owners to third party infrastructures is problematic in the context of security. Using public clouds as a deployment platform for applications and services is in most cases not suitable. Private cloud (clouds on private networks) maintained within an entity can help to solve this problem. The identified issues regarding outsourcing of data and reliability of infrastructures are not only specific to cloud infrastructures, but must be addressed for all kinds of distributed architectures.

2.1.2 Cloud Anatomy

The Cloud Computing paradigm replaces the classical multi-tier architecture model of web services and creates a new set of layers (Sun Microsystems Inc. 2009, ANSI 2009) as depicted in Figure 1. Software as a Service (SaaS) and data Storage as a Service (dSaaS) are the top layers and feature processing and storage facilities through web services. Platform as a Service (PaaS) is the middle layer and encapsulates complete development and runtime environments (for example operating systems, databases or web service application frameworks). Infrastructure as a Service (IaaS) is the bottom layer and delivers basic computational infrastructures as standardized services over the network. The bottom layer is then based on actual hardware provided to realize a cloud infrastructure.

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2 http://www.opencloudmanifesto.org/
2.2 Spatial Data Infrastructures

Spatial Data Infrastructures (SDIs) are technical, organizational and legal frameworks for geoinformation resources (McLaughlin and Groot 2000). SDIs can be designed differently. For instance, Bernard and Streit (Bernard & Streit 2002) especially focus on the service aspect of SDIs by specifying that an SDI enables the cooperatively use of distributed governmentally or privately held geodata and GI-Service across administrative and system borders. Whereas, McLaughlin and Groot (2000) emphasize the organizational aspect of “[…] delivering spatially resources, from the local level to the global level, in an interoperable way for a variety of uses.”

The building blocks of an SDI are the geodata, its technical network, metadata, Web Services and standards (BKG 2002). Specific Web Services provide the geodata and corresponding metadata the Web. To realize communication sufficiently, the services have to be interoperable through standardized interfaces. Onstrud (Onstrud 2007) adds clearinghouses, partnerships, education and communication to this definition. Clearinghouses are used to uniformly search distributed geodata and actually obtain the geodata. Partnerships reduce redundancy and costs. Education and communication enables different entities to communicate knowledge and thereby learn from each other.
Several initiatives are currently in the process of establishing SDIs on multiple levels. From a top-down point of view, on a global level there is i.e. DigitalEarth and on the European level INSPIRE (European Council 2007). Many countries have started to establish their own national SDI, for instance the USA (USGS 2005), Canada (Geoconnection 2004), Germany (GDI-DE 2007), Portugal (Juliao 2009) and Denmark (Jarmbaek et al., 2009).

To actually build SDIs, standards and best practices are required. The Open Geospatial Consortium (OGC) is dedicated to standardize SDI services to enable interoperable communication.

Overall, the main advantages of an SDI for the participating organizations and society are (Bernard et al. 2005):

- Cost effective data production
- Avoidance of duplications
- Efficient data exchange and use over administrative and enterprise borders
- Improvement of decision making on the basis of available high value data.

Based on the presented concepts, Section 3.1 will describe current obstacles in developing SDIs, which can be addressed by integrating the cloud paradigm.

3 Cloud-enabled SDIs

This section provides the design of a cloud-enabled SDI by applying the concepts introduced in Section 2. At first, Section 3.1 analyses obstacles of SDIs. The findings of this analysis are additional input to design a cloud-enabled SDI (Section 3.2).

3.1 Obstacles in SDI Development

SDIs have shown a great potential for enabling the market value of geoinformation as for instance presented in (Micus 2004). However, current SDI development faces different challenges as for example volunteered geoinformation and data harmonization (Craglia 2009). On this basis, the following obstacles can be identified in SDI developments with regards to cloud computing:

- Upfront costs barriers
- Mass market requirements
- Legally binding performance allowances
SDI literature mentions also other obstacles such as organizational aspects (Ollen 2003) which are not considered here due to less relevance to the cloud context.

Volunteered geoinformation is beneficial for SDIs to enhance the availability of real-time data, but appropriate concepts to integrate such geoinformation are not yet available (Craglia 2009). In particular, volunteered geoinformation collected by ordinary users, who in some cases can provide up-to-date data, play an important role especially in risk management scenarios (e.g. geotagged pictures of flooding taken by mobile phones). These geospatial mass market applications, as the name implies, typically yield many concurrent requests which have to be processed. As Scholten et al. show (Scholten et al. 2006) scalability is a problem for SDI services. To meet these requirements of mass market applications for immediate response (i.e. below 5 seconds), scalable solutions are necessary.

Another challenge is the integration of real value-added information, provided by web-based processing. As already mentioned, SDIs are currently in a transition of the focus from data (provider-oriented) to information (user-oriented) (Kiehle 2006, Schaeffer et al. 2009). To generate this information, thorough processing facilities have to be integrated into SDIs. This integration requires large investments in computational and storage resources to handle the intrinsic complexity and huge volumes of geodata (e.g. LIDAR or real-time sensor data) as well as multiple and concurrent requests by mass market applications. Apart from the investments in large-scale computation infrastructure for processing, other investments related to SDI development such as software license costs are typically have to be considered. These investments can be seen as a major obstacle towards the full implementation of SDIs. For instance, to build up the Swedish SDI, more than 150M $ by an annual maintenance cost of 30M $ are reported by (Wigberg 2002). The Italian SDI has already cost over 400M €. Even though most of the money has been spent on data collection, it becomes clear that operating SDIs at a technical level is cost intensive. This shows also the investment of 80M € for infrastructure services for the Italian SDI over a 2 year period (Cappadozzi 2008).

Additionally, SDI initiatives with legal bindings such as INSPIRE (legally binding since 2007) explicitly require guaranteed response times for specific queries (INSPIRE, 2007) (INSPIRE, 2008). For example, the current requirement for processing is a throughput of 1 MB/second and a response time of the service below 1 second. Search queries need to be answered within 3 seconds and services must be able to handle up to 30 of these queries at the same time. Image downloads should have a maximum response time of 5 seconds. To meet the specified performance boundaries in peak times, scalable solutions have to be found which are not yet implemented in SDIs from a technical point of view.
3.2 Design of a Cloud-enabled SDI

This section presents a concept of a cloud-enabled SDI, which integrates the Cloud Computing paradigm with the SDI concept.

In general, there are two options for realizing the integration of Cloud Computing and SDIs:

- Option 1: Adopting Cloud Computing principles and standards to SDIs.
- Option 2: Migrating SDI services on top of a Cloud Computing infrastructure.

Following option 1, SDIs are limited to themselves by creating separate standards and markets and could not benefit from mainstream-IT developments in the future. The authors of this paper favour option 2 which is more beneficial for the GI-domain as it is more open to the mainstream IT world and thereby broadens the opportunities of the GI-domain. Therefore option 2 would in contrast to option 1 allow the combination of SDI and Cloud Computing benefits, while benefiting from new developments in the mainstream IT world at the same time.

Mapping between SDI and Cloud Computing Components

From an architectural perspective, the integration of SDIs into Cloud Computing infrastructures is shown in Figure 2. In detail, data services (such as WFS) can be considered from a customer perspective as Software as a Service (SaaS), because they offer certain functionality, such as spatio-temporal query for datasets. From a data owner perspective, dSaaS is utilized, because the cloud can store the data served via standardized interfaces over a network. A typical case is a company for remote sensing, storing the large stream of data coming from their satellites and providing these images via data provision services to customers, without dealing with extending memory capacity in their IT infrastructure. SaaS as well as dSaaS rely on PaaS for e.g. the operating system, databases or web service containers, while IaaS describes the hardware level as shown in Section 2.1.2.

Processing instead of data storage aims at deriving information from data, can be seen as a typical SaaS application since customers can use the offered functionality, such as interpolating data on their side. The computation resources are provided via PaaS and IaaS. The same applies for portrayal services such as a WMS or discovery services e.g. Catalog Services (CSW).
The presented concept addresses the identified obstacles in SDI development (Section 3.1) as explained in detail in the following.

**Upfront costs barriers**

From a georesource (data/processes) provider perspective, the classic Publish-Find-Bind pattern of SOAs/SDIs (Figure 3) can be applied to the cloud-enabled SDI (Figure 4). According to this classic pattern the georesource providers host their services offering georesources on their own infrastructure and publish these services to a registry. This allows clients to find the georesources and bind (invoke) them. In other words, the georesources are accessed via services based on standardized interfaces over a network. This results in high upfront investments for the georesource owner to cover also peak loads or risk failing of the infrastructure.

Cloud Computing and in particular the aspect of outtasking can be utilized to overcome this high up-front investment for building and maintaining a large in-house IT infrastructure. By delegating computational and storage intensive tasks to third party providers in a cloud and using these tasks via services with standardized interfaces over a network, SDI services can be used in a cloud as shown in Figure 4.
Fig. 3. Classic Publish-Find-Bind SDI pattern

The classic Publish-Find-Bind pattern still applies here, but the georesource provider uses the cloud to host their georesources. Therefore, there is a distinction in this concept between the roles of the georesource provider and georesources host. While the provider still publishes georesources which the customer can discover, the found georesources are bound from the cloud. Therefore, a business relationship has still to be established between the customer and the georesource provider. The revenue model for the georesource provider can be arranged in a flexible way. For instance, on-demand or flat-rate access models may be adequate as they are also the dominated revenue model in public cloud environments such as Google Apps Engine or Amazon Elastic Compute Cloud (Amazon EC2\(^3\)).

Besides, by using standardized service interfaces, cloud infrastructures hosted by different providers can be used interchangeably from a cloud service consumer perspective. In other words, a client application does not need to be aware of whether a service is hosted in a cloud or not and which cloud provider is used. However, different cloud providers still have different internal requirements and capabilities which make it more complicated for the georesource provider to switch clouds for setting up a service in different clouds.

\(^3\) For a complete cost schema, see http://aws.amazon.com/ec2
Mass market requirements

As identified in Section 3.1, current SDI concepts lack scalability, which is especially crucial for integrating mass-market applications into SDIs. SDIs can benefit from the ability of cloud infrastructures to handle large amounts of requests, processes, or data. By migrating services into the cloud, the georesources provided by these services are immediately available in a scalable fashion for on-demand use. Figure 5 shows how the cloud expands from light blue over light violet to blue with the increasing number of user induced requests.

Conceptually, the scalability is automatically available through the cloud without touching the services itself. This implies that existing services can be deployed in a cloud environment without any adjustments to the service implementations.

When deploying SDI components on a cloud infrastructure, they can benefit from the cloud's scalability instantly, but still remain interoperable. Regarding the service interface, there is no difference between a cloud-enabled SDI service and a non-cloud enabled SDI service. In fact they can be used interchangeably and/or sequentially (in a composed workflow of traditional and cloud-enabled SDI components).
Legally binding performance requirements

Existing SDIs which implement a legal framework such as INSPIRE have to meet specific Quality of Service (QoS) parameters as described in Section 3.1. This applies also for private companies providing SDI services which typically have to provide specific QoS levels. Especially the scalability aspect of clouds can help here to process even a large amount of requests in a given time frame. This aspect can be combined with the argument of up-front investments as described before. For instance, for start-up companies the legally binding performance requirements can be a limiting factor to realize innovative ideas if large infrastructure have to be acquired a priory to comply to the performance requirements. The Cloud Computing paradigm can be used to solve this obstacle, because it offers a low-cost way of delegating the performance requirements to a specialized third party georesource host (cloud provider).

For SDIs, this means, that the services of georesources have to be deployed in the cloud as shown in Figure 4.

These theoretic considerations concerning cloud-enabled SDIs will now be evaluated against the background of a real world use case with a special focus on the scalability of cloud-enabled SDI services over existing SDI services.

4 Application of the Use Case for a Cloud-enabled SDI

The scenario is settled in the context of a public risk management use case, in which in-situ-sensor data has to be analyzed for assessing a fictive fire threat in Tasmania. A similar scenario and involved services have been extensively presented in Foerster & Schaeffer (2007) for the area of north-west Spain. This section pushes the scenario idea one step further and leverages cloud enables services to create a highly scaleable solution in Tasmania.
The Amazon Web Services (AWS) together with an OGC Web Processing Service implementation hosting a buffer and intersection process is used in this scenario.

The Amazon Web Services product is a collection of services that are offering Infrastructure as a Service (IaaS), Data storage as a Service (dSaaS) and some aspects of Platform as a Service (PaaS). The Amazon EC2 provides a web service interface to manage virtual machines (IaaS) that are used to host customer specific applications and can be scaled on-demand to handle peak load. The Amazon Simple Storage Service (Amazon S3) provides a web services interface that can be used to store and retrieve large amounts of data (dSaaS).

To deploy a WPS in Amazon EC2 and thereby to add the SaaS layer, an Amazon Machine Image (AMI) has to be configured. The AMI serves as a template for all instances that have to be setup by the Amazon cloud. Therefore, a WPS has to be installed on the virtual machine following the AMI template on top of a chosen machine setup (IaaS), operating system and servlet container (PaaS). In addition, the whole setup has to be configured to match certain scalability goals (expressed as rules). For this use case, the following rules were applied:

- 1 instance should be running at all times
- a maximum of 12 instances can be created
- if the CPU workload is below 20% in a 30 second interval, the number of instances should be decreased by 1
- if the CPU workload is above 50% in a 30 second interval, the number of instances should be increased by 1.

Once, the AMI is configured, deployed and started, the WPS is accessible via a single URL like any other non cloud-enabled WPS. For instance a standard web client such as OpenLayers or directly as a web service can be used to consume the service. In the given scenario, an expert would discover the URL (find) add the service to the OpenLayers client (bind) and buffer the given wild fire polygons. The resulting layer is then intersected by the given Tasmania road data.
Towards Spatial Data Infrastructures in the Clouds

Fig. 6. Result (in red) of cloud enabled WPS intersecting buffered wild fires (violet) and road data (yellow) in Tasmania.

Overall, this allows the user to assess which parts of the road infrastructure are at risk by a fire (see Figure 6, read layer). With an increasing number of requests, the number of WPS instances in the cloud should increase as shown in Figure 5 to meet the scalability goals (i.e. constant response times) (see Section 5 for detailed results). In such risk management situations, in which multiple users with concurrent requests are expected and peak loads on the infrastructure are common, the information about the latest wild fires will still be processed and provided to the user based on real-time processing. The following section examines a stress test simulating such peak loads on the infrastructure and thereby demonstrates the scalability of cloud-enabled SDIs.

5 Stress Test

To demonstrate the scalability of cloud-enabled SDIs, we used a stress test to simulate an increasingly high demand of simultaneous requests (i.e. peak loads). A constant response time by the WPS deployed in the cloud was expected in contrast to a linear rising response time by a non cloud setting. The WPS was stress tested with the simple buffer algorithm, deployed in the Amazon Web Service framework as well as on a local and non cloud-enabled Tomcat installation. The geodata for that process was also delivered via a web service (deployed at the cloud(s) in the first case and deployed on the local and non cloud-enabled machine in the second case).
5.1 Methodology

A cumulative approach was used, starting with 1 and up to 200 requests that were sent nearly simultaneously in a short period of time to the deployed services. The elapsed time from sending the request to receiving the response on its own, as well as for the cumulative sum of the requests/response times was measured. In order to compare the local setting with the remote cloud settings, the results are normalized by only regarding the response time relatively to the maximum/minimum interval of all requests to the specific machine.

5.2 Results

Figure 7 shows the normalized response time of the online (Amazon Web Services) as well as of the local deployed WPS over the number of simultaneously sent requests. Normalization was reached by means of using the interval (min, max) as baseline. The response time of the remote WPS (monotonically increasing line) stays nearly constant up to 200 simultaneous requests whereas the local WPS response time (constant line) grows linearly. For the cloud approach, only one large peak at the beginning can be observed at the beginning and some smaller peaks during the rest of the execution.

Fig. 7. WPS local vs. WPS in the cloud stress test results

5.3 Evaluation

The performance evaluation shows to some degree that a WPS deployed in the Amazon Web Service scales at high request rates as expected: The response time for many simultaneous requests stays nearly constant in contrast to the non-cloud deployment.
The peak in the beginning of the cloud curve (Figure 7) for the measured response times could be explained by means of managing the (virtual) server instances in the backend. Additionally, the number of instances is increased only by 1 in a 30 second interval, which means, that for the starting period not enough instances are available. We assume that the smaller peaks for the remote WPS are also related to minor background management tasks, such as setting up new instances.

6 Conclusion

This paper presents an approach for integrating SDIs and Cloud Computing technologies to set up a cloud-enabled SDI. A cloud-enabled SDI is identified as beneficial to address the major obstacles of SDI development (Section 2). Different roles in this cloud-enabled SDI are distinguished (Section 3). When integrating Cloud Computing and SDIs the existing publish-find-bind pattern for service interaction can be reused. Therefore, we see a paradigm shift from technological to economical aspects in contrast to a complete paradigm change, because the technical principles stay the same while economical aspects (upfront costs, maintenance, cost-effective production, etc, see section 1) motivate the technological shift.

It also became clear, that the way forward is to bring SDI components into cloud environments instead of adopting mainstream IT techniques such as Cloud Computing for SDIs. This will broaden the business opportunities for SDIs based on the high potential of cloud technologies. Therefore, we can foresee that the components, once deployed in an SDI, could be part of a cloud infrastructure service (belonging to PaaS) as there are already for instance databases or authentication APIs provided in a cloud, for georesources (geoprocessing/geodata).

As discussed, cloud interoperability from a client perspective is given for the geospatial domain because of the well established standards. From a provider perspective, the coupling with each cloud infrastructure is vendor-specific. Therefore, the advance of the SDIs regarding standardization can lead to easy cloud interoperability also for the provider in respect to georesources. Once the standardized SDI services are deployed in a cloud, they can be used by other cloud applications interchangeably. This implies that when a georesource dependent application is migrated from one cloud provider to another, the connection to underlying georesources providing services does not need to be changed due to its standardized access.

Another conclusion we can draw is, that Cloud Computing has the potential to create new business models for SDIs. These business models have to be distinguished from client and provider perspective. From a client perspective,
the low up-front investment barrier by using cloud environments for SDI services allows companies to start new business models, which may have not been possible before due to high legally binding requirements. Besides, the outtasking of non-core task of a business process can lead to a modification of exiting business processes, which allows the overall business model to be more flexible to customer needs. This can lead on the provider perspective to specialized SaaS providers which can offer value-added services on-demand in a scalable fashion as for instance shown in the use case. These new SDI business opportunities have to be studied further in the future. Especially, the increasing distribution of smartphones seems to be a promising market, because applications on smartphones typically address the mass market but also lack large processing, storage and battery capacities, which makes it necessary to handle the data in a remote server environment such as the cloud.

The use case and further tests on the scalability part showed that cloud computing keeps its promises in terms of scalability. It could be clearly seen, that the response time stays constant in contrast to a linear increasing response time for a non-cloud approach.

As already discussed in Section 2.1, privacy can be a concern for sensitive data when they are given away to third party public cloud providers. The same problem applies to SDIs and the georesources provided via services in particular, because georesource could e.g. cover sensitive areas such as government buildings or are costly to create. However, certified cloud providers in analogy to certified tax accountants can be one applicable solution to overcome privacy concerns.

References


Increasing the Availability of Spatial Data held by Public Sector Bodies: Some Experiences and Guidelines from the OneGeology-Europe Project

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Abstract

This paper provides an overview of the OneGeology-Europe project's work on the harmonisation of access and licensing policies of the national Geological Surveys in the European Union. After presenting the European legal framework for the availability of public sector spatial data, it sets out some of the main challenges for harmonising data policies and the activities that were undertaken in the OneGeology-Europe project to address these challenges. These activities include the creation of a Code of Practice and model licences.

Keywords: spatial data, access, re-use, sharing, data policy, legal framework, licences, licensing, code of practice.

1. INTRODUCTION\textsuperscript{1}

In the 21st century information society, the importance of information created or held by the government has become impossible to deny. Government is one of the largest producers of information in many areas, such as business information, health data, geographic data, and legal information. Opening up these resources for broader use has become an important objective in many of the European Member States. This paper gives some recommendations on guidelines for the

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opening up of a particularly important subset of public sector information, i.e. spatial data.

1.1 The Role of Public Sector Information in the Information Society

Access to public sector information (PSI) is extremely important in a democratic state. Citizens should be able to consult data held by the public bodies in order to participate fully in the democratic society, and to hold their government accountable for its actions. The development of the information society and the growing possibility for citizens to make their opinion heard (via e-mail, blogs, discussion forums, etc.) has only increased the call for PSI (Janssen, 2010; Bovens, 2002). However, PSI also has a considerable socio-economic value, in that its availability can be an important stimulus for economic growth and societal cohesion. As was recognized by Mayo and Steinberg in their Power of Information Review, PSI is an essential basis for digital information products and services and it can be used like “a glue to bind together disparate information”. Thirdly, PSI plays a crucial role in fulfilment of the public task by the public administration. PSI is created mainly to support the development and implementation of public policy. Information collected or created for one particular statutory need can often also be used for the performance of other public tasks within the same organization or by other public bodies. Hence, the sharing of PSI allows public bodies to avoid duplication of costs and efforts and enables to engage the saved resources in other public initiatives (Janssen, 2010). The integration of information from different sources supports better decision-making and can improve the public sector’s internal data management policy and practices.

1.1. Spatial Data

One of the categories of PSI, of which the exchange is particularly important, is spatial data, which can be defined as “any data with a direct or indirect reference to a specific location or geographical area” (European Parliament and Council, 2007).

Already in the 1990s, the European Union intended to regulate the sharing of spatial data between public bodies. While GI2000 was never realized, the underlying ideas were taken up again in the INSPIRE initiative, which led to the 2007 Directive establishing an Infrastructure for Spatial Information in the European Community (INSPIRE directive) (European Parliament and Council, 2007). A main objective of this directive is “that it is possible for spatial data collected at one level of public authority to be shared between other public authorities” (see recital 6 INSPIRE directive).
The INSPIRE directive is not the only directive regulating the availability of spatial data from public sector bodies. The Directive on the re-use of public sector information (PSI directive) (European Parliament and Council, 2003a) and the Directive on public access to environmental information (Access directive) (European Parliament and Council, 2003) also play an important role in opening up public sector spatial data. INSPIRE intends to increase the exchange of data between public bodies; the PSI directive deals with the re-use of PSI outside of the public task and wants to stimulate the information market; and the Access directive is focused on increasing accountability and public participation through access to environmental information. However, the scopes of these directives overlap and the rules they contain are not always consistent (Janssen, 2010). In addition, the disparate application of the three different instruments by public bodies holding various types of spatial data can lead to large differences and lack of clarity in their policies for disseminating data. In order to prevent confusion about the applicable conditions for obtaining spatial data from a public body, a solution would be a common data policy taking into account all the relevant legislation and applying as many common building blocks for any type of use as possible. The provisions of the Access Directive, the PSI Directive rules and the INSPIRE Directive provisions should all be taken up in a harmonized, transparent and legally compliant data policy for public bodies providing spatial data. Ideally, in order to ensure easy access of users wanting to combine spatial data from different sources, these data policies would be harmonized based on a number of common guidelines.

This paper describes the work done in the OneGeology-Europe project on access and licensing of geological spatial data, and sets out the main guidelines for data policies developed in the course of this project. The following section will present the legal grounds that should be used for constructing a list of requirements for these data policies, i.e. the Access directive, the PSI directive, and the INSPIRE directive. Next, we will present some challenges for the harmonization of public bodies’ data policy and how these challenges were tackled during the course of the OneGeology-Europe project. Finally, the role of model licences will be addressed and some proposals for simplifying the licences for spatial data will be made.

2. EU LEGAL FRAMEWORK

The legal framework that needs to be taken into account by each public body creating a policy for making its spatial data available is based on the national transpositions of the INSPIRE directive, the Access directive and the PSI directive. This paper is based on the general rules offered by the directives, which should be the same in each Member State.
2.1. INSPIRE Directive

The INSPIRE directive was adopted on 14 March 2007. The directive aims to establish an infrastructure for spatial information in the European Union for the purposes of environmental policy and other policies or activities which may have an impact on the environment. It facilitates the sharing of spatial data sets and services between public bodies for their public tasks relating to the environment by imposing technical and organisational requirements, with regard to metadata, the creation of network services, data specifications, organisational measures for data sharing, coordination and monitoring and reporting (European Parliament and Council, 2007). The directive was to be transposed by Member States by 15 May 2009. However, only very few countries made that deadline.

According to article 17.1 of the INSPIRE directive, each Member State has to adopt measures for the sharing of spatial data sets and services between its public authorities, enabling these public authorities to gain access to spatial data sets and services, and to exchange and use those sets and services for the purposes of public tasks that may have an impact on the environment. Staff members of a public authority should be able to access spatial data when they need it, without “any practical obstacles at the point of use”. While charging for and licensing spatial data sets and services remains possible, this has to be compatible with the general aim of INSPIRE to facilitate data sharing. Possible charges are limited to “the minimum required to ensure the necessary quality and supply of spatial data sets and services together with a reasonable return on investment, while respecting the self-financing requirements of public authorities supplying spatial data sets and services, where applicable” (European Parliament and Council, 2007).

The INSPIRE directive also contains provisions on access of the public to spatial data via the network services. These provisions are without prejudice to the Access directive (see article 2 of the INSPIRE directive), so the possible limitations on access of the public to the network services are aligned with the exceptions in that directive. Public access to discovery services has to be free of charge. This also applies to view services, unless charges would secure the maintenance of the spatial data sets and services, particularly in cases involving very large volumes of frequently updated data, such as meteorological data (see article 14 of the INSPIRE directive). These organisations would not be able to collect, produce and update spatial data if they could not recover any costs by charging the public for viewing their data (Janssen, 2010). Other services, such as download services, can be charged for by the public bodies without any restrictions.
2.2. **PSI Directive**

The PSI directive aims to promote the re-use of PSI by establishing a minimum set of rules governing the re-use of existing public sector documents and the practical means of facilitating this re-use (European Parliament and Council, 2003). Re-use includes “the use by persons or legal entities of documents held by public sector bodies, for commercial or non-commercial purposes other than the initial purpose within the public task for which the documents were produced” (see article 2.4 of the PSI directive). Hence, re-use includes any use falling outside of the public task, whether commercial or non-commercial. For example, this could involve the use of PSI by commercial publishers, start-up companies, consultancy firms, but also non-governmental organisations, students, or researchers.

As a basic principle, the Member States and the public bodies are not under any obligation to make their data available for re-use. If they choose to do so, they have to make the data available under specific conditions, including time limits, available formats, fees, licensing and transparency. The total income from charges for re-use cannot exceed the cost of collection, production, reproduction and dissemination, together with a reasonable return on investment (see article 6 of the PSI directive). While allowing this broad margin of appreciation, at the same time the directive asks the Member States to encourage their public bodies to charge only marginal costs for reproduction and dissemination (see recital 14).

Whatever conditions are imposed by the public bodies on the re-use of their data, they have to be non-discriminatory for comparable categories of re-use (see article 10 of the PSI directive). The directive suggests possible different conditions for commercial or non-commercial re-use, but it does not indicate whether all commercial re-use should be considered comparable. To avoid the risk of cross-subsidies between the public task activities and the commercial practices of a public body, the PSI directive requires the public bodies to apply the same conditions and charges to their own re-use as they do towards other re-users (see article 10.2).

2.3. **Access Directive**

The 2003 Access directive implements the provisions of the 1998 Aarhus Convention in the European Union. The obligations of the Member States under the Aarhus Convention are divided into three main pillars: access to information, public participation and access to justice. These three aspects should contribute to the protection of the right of every person to live in an environment adequate to his or her health and well-being (United Nations Economic Commission for Europe, 1998). The Access directive only addresses the first pillar of the Convention (European Parliament and Council, 2003). It aims to guarantee the right of access to environmental information held by or for public agencies and to
ensure that environmental information is progressively made available to the public (see article 1 of the Access directive). It contains provisions both on access on request and on proactive dissemination of information by the public authorities.

As a general principle, public authorities have to make available environmental information held by or for them to any applicant, without the applicant having to state an interest. Possible exceptions to this general right of access include situations where disclosure of the information would harm e.g. the confidentiality of the proceedings of public authorities; international relations, public security or national defence; the course of justice; intellectual property rights; the confidentiality of personal data; or the protection of the environment (see article 4 of the Access directive). Each of these possible exceptions has to be interpreted in a restrictive way and weighed against the interest in disclosure. As was mentioned earlier, the exceptions from the Access directive were copied literally in the INSPIRE directive provisions on public access to the network services, in order to ensure coherence.

The Access directive ensures free of charge on-site viewing of environmental information, while charges for the supply of information may be up to a reasonable amount (see article 5 of the Access directive). Such a reasonable amount can in principle only include the actual costs of production of the information, but market charges can be allowed when a public body makes its environmental information available commercially in order to guarantee the continued collection and publication of such information.

The Access directive also obliges public authorities to make their environmental information proactively available, as much as possible via electronic means.

2.4. Relationship between the Three Directives

2.4.1. Comparison of the Main Provisions of the Three Directives

The table below provides a comparative overview of the main provisions of the Access directive, the PSI directive, and the INSPIRE directive.
<table>
<thead>
<tr>
<th></th>
<th>INSPIRE Directive</th>
<th>PSI directive</th>
<th>Access directive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope</strong></td>
<td>• Spatial data sets and services falling under the</td>
<td>• Public sector documents</td>
<td>• Environmental</td>
</tr>
<tr>
<td></td>
<td>themes listed in Annex I, II and III</td>
<td>o No documents the supply of which is an activity falling outside</td>
<td>information</td>
</tr>
<tr>
<td></td>
<td>• Public authorities</td>
<td>the scope of the public task; no third party IPR; no documents that are</td>
<td>Public authorities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not accessible</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Public sector bodies (no cultural institutions, no research and education</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>institutions, no public broadcasters)</td>
<td></td>
</tr>
<tr>
<td><strong>Electronic/paper</strong></td>
<td>• Only electronic</td>
<td>• Electronic + paper</td>
<td>• Electronic + paper</td>
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<td></td>
<td></td>
<td>• Electronic where possible</td>
<td>• Electronic where</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>possible</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>• Data sharing for public tasks with an impact on the</td>
<td>• Use for commercial and non-commercial purposes outside of the public task</td>
<td>• Access of the citizen</td>
</tr>
<tr>
<td></td>
<td>environment</td>
<td></td>
<td>on request</td>
</tr>
<tr>
<td></td>
<td>• Public access to network services</td>
<td></td>
<td>• Dissemination to the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>public</td>
</tr>
<tr>
<td><strong>Obligatory</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
<td>• Data sharing</td>
<td>n/a</td>
<td>• The information</td>
</tr>
<tr>
<td></td>
<td>o Course of justice, public security, national</td>
<td></td>
<td>requested is not</td>
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<td></td>
<td>defence or international relations</td>
<td></td>
<td>held by or for the</td>
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<td></td>
<td>• Public access</td>
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<td>addressed public</td>
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<td></td>
<td>o Discovery services</td>
<td></td>
<td>authority to which</td>
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<td></td>
<td>• International relations, public security or</td>
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<td>the request is</td>
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<td>national defence</td>
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<td>addressed.</td>
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<td>• The request:</td>
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<td>o Is manifestly</td>
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<td>unreasonable.</td>
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<td>o Is formulated in</td>
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</table>
Other services: the confidentiality or protection of a.o. international relations, public security or national defence; intellectual property rights; personal data; the environment to which such information relates (location of rare species).

Concerns material in the course of completion or unfinished documents or data.
Concerns internal communications that cannot be disclosed.

- The disclosure of information would adversely affect the confidentiality or protection of a.o. international relations, public security or national defence; intellectual property rights; personal data; the environment to which such information relates (location of rare species).

<table>
<thead>
<tr>
<th>Charges</th>
<th>Data sharing</th>
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</thead>
<tbody>
<tr>
<td>• Data sharing</td>
<td></td>
</tr>
<tr>
<td>o Reporting obligations: no</td>
<td></td>
</tr>
<tr>
<td>o Other data: yes, minimum required to ensure the necessary quality and supply of spatial data sets and services together with a reasonable return on investment, while respecting the self-financing requirements of public authorities supplying spatial data sets and services, where</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Total income should not exceed the cost of collection, production, reproduction and dissemination, together with a reasonable return on investment. Marginal cost is encouraged</td>
</tr>
</tbody>
</table>

- Examination on site: no
- Supply: yes, not exceeding a reasonable amount
  - Not exceeding actual costs of producing the material in question.
  - Market-based charge, if public authorities make available environmental information on a commercial basis, and where this is necessary in order to guarantee the continuation of collecting and publishing such
applicable.
- Public access
  - Discovery services: no
  - View services: no, except where charges secure maintenance of spatial data sets and services
  - Other services: yes

| Assets registry | Yes | Yes | Yes |
| Model licences | Public access: disclaimers, click-licences or, where necessary, licences possible | Yes. Where licences are used, standard licences for the re-use of public sector documents, adaptable to particular licence applications, should be available in digital format and could be processed electronically. | n/a |
| Time limits | n/a | Yes | Yes |
| | Within reasonable time, but no longer than 20 days after the receipt of the request. In case of extensive or complex requests the limit may be extended by another 20 days. | As soon as possible, or at the latest within one month from the request. In case of a high volume or complexity of the information, within two months from the request. |
2.4.2. Complications in the Relationship between the Directives

While the INSPIRE directive, the Access directive and the PSI directive all stimulate the availability of spatial data held by the public sector, each directive has its main objectives and target group. The INSPIRE directive mainly addresses the sharing of spatial data between public authorities for the performance of their public tasks, while the PSI directive applies to any use of PSI outside of such public tasks. In essence, the PSI directive aims to stimulate economic growth by encouraging the re-use of PSI, contrary to the Access directive, which is based on the democratic objectives of transparency, public participation and accountability. However, the distinction between these objectives (and hence the applicability of the directives), is not always easy to make.

For instance, it is not always clear whether a company is asking for access to particular environmental data to ensure that the public body involved has made a legitimate decision, or whether it wants to re-use this data for its commercial benefits. In many cases, requests for data will not only be motivated just by the need of the public to know what its government is doing, but also by a personal gain that can be obtained from having the data (Holland, 1997; Peterson Dando, 1994). In this way, it is impossible to determine the applicability of the PSI directive or the Access directive. Next, applying the INSPIRE directive to a request for spatial data from a public body is also not self-evident, as this public body may be using these data for its public task or for other activities that remain outside this public task. In the latter case, the PSI directive should apply.

In addition, even if it would be clear for which purpose a particular spatial data set or service is required, the interpretation of the applicable rules may still cause issues. For instance, in the case of public access to the network services foreseen in the INSPIRE directive, one could question how to interpret the provisions on the charges for these network services. As the INSPIRE directive is without prejudice to the Access directive, the provisions of the latter prevail if they both apply (i.e. to spatial data that could also be qualified as environmental information) and there would be a contradiction between the two pieces of legislation. If the rules of the INSPIRE directive stay within the boundaries set by the Access directive, they can be applied without restraint. However, even though the Access directive refers to electronic means, it seems to have been written with the traditional concept of documents in mind. When this is combined with the obligations of the INSPIRE directive on access to the network services, it remains unsure whether view services should be seen as a form of supply of data, or rather as analogous to examination *in situ*, which is free of charge under the Aarhus directive (Janssen, 2010). In the latter case, any charges for viewing services, regardless of the situation, would be impossible. For now, it remains up to the European Court of Justice to decide on the interpretation of both directives.
Ideally, a public body intending to disseminate data should not have to worry about which rules to apply to the provision of its data, but only about the concrete questions whether it wants to impose conditions or require charges for the use of its data, and how to build relationships with its users. However, this is not so easy to achieve, and requires the conscious development of a data distribution policy that enables the decision-makers within the public body to make quick and consistent decisions on each request for data, while still complying with all legal requirements.

3. CHALLENGES FOR HARMONISING DATA POLICIES

A public body’s data policy can be described as a policy detailing the functioning and decisions of the public body with regard to the data it holds and intends to disseminate. Such a policy defines the rules on the basis of which data are provided to interested users. In order to enhance the availability of public sector spatial data throughout the European Union, these data policies should be harmonised as much as possible. Three levels of harmonization should be considered.

First, any harmonized data policy should combine rules from the three Directives mentioned above. Even though the scopes of the directives overlap to some extent and their provisions are not always consistent, a common ground between them can be found. The overlap, if looked at from a positive perspective, provides a common denominator that could constitute a basis to reconcile the existing discrepancies. Only by bringing together the varying provisions of the PSI directive, the INSPIRE directive and the Access directive, a consistent data policy can be built.

Second, such a policy should preferably also be created in cooperation between multiple public bodies holding different categories of spatial data sets or even other types of data. This cooperation should ensure consistency between the policies governing access to and use of spatial data held by diverse bodies, in this way increasing the legal certainty for a user requesting data from different public bodies. While this might appear as an extremely ambitious goal, the common ground constructed by the EU legislation on the availability of spatial data provides a good first basis for such a harmonized approach that can at least increase the transparency and the dialogue between the different public bodies within a Member State. The Access Directive, the PSI Directive, and the INSPIRE Directive can be used as building blocks to design a list of requirements for data policies for public bodies. However, the three directives do not provide a full list of aspects that need to be taken into account in the development of a well-functioning data policy. A broader view on the necessary elements of data policies is required. This involves possible solutions that might not be strictly
stemming from the aforementioned documents, but which could be derived from a common practice that has been successfully employed by certain public bodies.

Third, in the attempt to enhance the availability of spatial data, it should not be forgotten that consistency between data policies should also be aimed for among different organizations across the European Union. Next to complying with the harmonized rules stemming from the European Union, the public bodies also have an obligation to obey any extra rules in the area of data availability imposed by their national legislations. In addition, it should not be forgotten that different countries across the European Union have diverse traditions of disseminating public sector spatial data. In some countries data have generally been available on a free or marginal cost basis for decades, without any restricting conditions, while public bodies in other Member States have developed a more complicated and restrictive policy. Such different approaches, relying on both legislation and tradition, cannot be changed easily. Any attempt to merge them into one common European approach will be a lengthy and difficult process. Next, the level of development of the different public bodies disseminating spatial data also has to be taken into account. Considerable differences exist between public bodies that are only starting to create a data policy and those that already have a broad experience with requests for their data.

Addressing the challenges mentioned in the previous paragraph requires a realistic, stepwise approach that does not focus on obtaining full harmonisation (or even uniformisation) of all policies for disseminating public sector spatial data in the European Union, but that rather starts with focusing on the transparency of data policies and with providing general principles and practical tools for the public bodies to implement their data policy. A realistic solution is to construct a flexible model of data policies – a generic tool that could be used by various public bodies providing data, leaving them the choice between a number of policy options that best fit their requirements and traditions. At the same time, the public bodies should be encouraged to choose the policy options that most increase the availability of spatial data and stimulate a user-friendly and practical approach to disseminating data.

4. TOWARDS HARMONISATION OF DATA POLICIES IN THE ONE GEOLOGY-EUROPE PROJECT

4.1. Introduction

The eContentPlus project OneGeology-Europe took a realistic approach, by creating a Code of Practice setting out the main components for a data policy for the national Geological Surveys participating in the project. The OneGeology-Europe project was carried out between September 2008 and October 2010 and aimed to create a dynamic digital geological map for Europe and make a
significant contribution to the progress of INSPIRE, by developing systems and
protocols to better enable the discovery, viewing, downloading and sharing of
core European spatial geological data (see www.onegeology-europe.org). This
also included addressing the licensing aspects of sharing geological data. In a
dedicated work package, an access and licensing policy was developed for the
geological surveys that could also be applied in other spatial data sectors.

This data policy was developed in a number of steps. First, the EU legal
framework was studied and a comparison was made between the Access
directive, the INSPIRE directive and the PSI directive, in order to get a clear
overview of the applicable rules that are harmonised on the European level. Next,
information was gathered about the current practices and challenges of the
geological surveys and of the data users that were partners in the One-Geology
project. A workshop was held in March 2009 to gather information on the
problems the Surveys were struggling with in making their data available and the
requirements of the users for obtaining the data in an efficient and workable
manner.

More detailed information about the applied conditions and charges for geological
spatial data were gathered through a questionnaire sent to all Geological
Surveys. In addition, in depth case studies were carried out of two of the
Geological Surveys that were considered to have the most differing information
policies and business models, i.e. the British Geological Survey (BGS) and TNO,
the Dutch research organisation that has taken up the role of the Dutch
Geological Survey. A generalised and simplified overview of some of the results
of the questionnaire is given in the table 2.

The case studies of TNO and BGS showed two very different data policy models,
with BGS having an intricate licensing system supported by a fully developed
licensing department, and TNO making its data available at no cost or a limited
annual fee, with only limited restrictions and without any dedicated staff. Any
harmonised data policy should be able to accommodate the differences between
these models and at the same time streamline them where possible.

To achieve a feasible result, the data policy that was developed within the project
contained two main elements: guidelines for implementing a policy and practice
with regard to requests for information for all Geological Surveys, and a number
of licensing models that left room for adaptation to the particular circumstances of
the geological surveys that were supposed to use them. A draft Code of Practice
holding these two elements was presented to the geological surveys and the
users in a workshop, and the final version was prepared on the basis of feedback
from the workshop and from stakeholders outside the project, such as members
of related EU-projects. While the Code of Practice was directed towards
organisations holding a particular type of spatial data, i.e. the Geological Surveys,
its guidelines and model licences could also apply to other types of spatial data that are disseminated by public bodies (Kuczerawy et al., 2010). In this way it can contribute to the harmonisation of policies for disseminating spatial data on a broader level.

Table 2: Overview of the Questionnaire Results

<table>
<thead>
<tr>
<th>How is your organisation financed?</th>
<th>100 % self-financed</th>
<th>100% state financed</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Has your organisation developed a policy for making geological data available?</td>
<td>Yes, in an official document (law, decree, regulation, etc.)</td>
<td>Yes, in an internal document/policy</td>
<td>We are preparing a policy</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Do you make a distinction between or have special conditions for types of users? (more than one answer possible)</td>
<td>(non)commercial</td>
<td>Science/education</td>
<td>Students</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Do you charge for supplying your data? (more than one answer possible)</td>
<td>Per use</td>
<td>Per year</td>
<td>Fixed fee</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>How information on the charges is made available to the users?</td>
<td>Standard charges on the website</td>
<td>Standard charges provided on request</td>
<td>Price determined ad hoc</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>What type of conditions do you impose? (more than one answer possible)</td>
<td>Attribution</td>
<td>Registration</td>
<td>Security measures</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

In the following section, some main guidelines of the Code of Practice for developing a data policy will be set out, focusing on transparency and user-friendliness. Next, attention is given to the model licences, which were built on the basis of existing model licences, adapting them to the needs of the Geological Surveys. The Code of Practice can be found on the OneGeology-Europe website and on the website of the Interdisciplinary Centre for Law and ICT (http://www.law.kuleuven.be/icri/deliverables/2071G-E_WP7_D7.pdf?where=).

2 15 Geological Surveys participated in the questionnaire. The information represents the situation in 2010.
4.1. Guidelines for Public Bodies’ Policy for Disseminating Spatial Data

Any policy encouraging the dissemination of public sector spatial data should be based on two main principles: user-friendliness and transparency. It is paramount for the success of any data dissemination policy that it starts from the needs of the user, rather than the supplier of the spatial data, and that it uses a simple, overarching approach, preferably with minimal differences between different types of users, data sets, types of use, etc. Transparency should appear on all levels: allowing users to know which data exists, where they can find it, how they can obtain it, under what conditions they can use it, and what they have to pay for it. In short, users should be properly informed about their rights and obligations. Only when armed with such information they can fulfil their needs and make sure that their rights are respected.

To ensure this transparency and user-friendliness, the public bodies’ data policy should be built around the different phases of a possible request for data from the point of view of the user. Its design should be intuitive and follow the natural steps taken by a user in the process of requesting, obtaining and using spatial data. This user-centric approach should ensure that all elements of the process are taken into account and that the user knows what to do in each stage of the process.

In the following subsections, we will highlight some of the aspects of the data policy described in the OneGeology-Europe Code of Practice, including the practical arrangements, metadata, request procedures, contact points, and conditions for access and use of the spatial data. However, all these aspects are irrelevant if they are not preceded by the appointment of a responsible person for the development and follow-up of the public body’s data policy.

4.1.1. Data Policy Officer

Public bodies need to think about how to organise their data dissemination and how to implement a data policy within their organisation. They should assign the responsibility for this data policy to a particular person or department within the public body, i.e. a data policy officer. This person or department should have a clear mandate to develop measures to improve the dissemination of the public body’s spatial data. The person or department responsible for the policy should in its turn make sure that its activities are known by all staff members of the organisation. Any staff member receiving a question from a potential user can refer this user to the appropriate people.

4.1.2. Practical Arrangements for Finding Spatial Data

Potential users of spatial data often do not know where they can find the data they need, or sometimes even what data they need. Spatial data should be easy to locate. A first point of entry is a portal, such as the geoportals being set up.
under the INSPIRE directive. Next, the discovery services required by INSPIRE will enable the search for spatial data and services based on the metadata provided for them. This should also satisfy the obligation of the EU member states under the PSI directive to take the necessary measures to ensure that practical arrangements are in place to facilitate the search for data. We will come back to the issue of metadata in a separate subsection.

While portals, discovery services and metadata should already be of great value to the user to find the data he or she needs, public bodies should realise that users may still have several questions left after consulting the metadata. In addition, some users may not find the data via the portals and discovery services, but by other means, such as own experience or guessing, advice from colleagues or business partners, unstructured information on websites, etc. These users should be directed to the data policy officer if they need more assistance. This entails that the website of the public body should clearly indicate the details of a help desk or at least a contact person who can answer the questions of the users or refer them to the right department. Contact details should include e-mail address and phone number, and preferably a contact person should be available that can assist possible users not only in the national language, but also in English and/or the language of a neighbouring country.

The assignment of a contact point fulfils the obligations of article 3.5 of the Access directive, which requires that officials should support the public in seeking access to environmental information and that information officers are designated. In addition, it can also be considered a practical arrangement that should facilitate the search for re-usable documents under article 9 of the PSI directive.

4.1.3. Request Procedure

Next, the request procedure is a crucial point of the data policy for the users. Public sector spatial data providers should develop a clear procedure for handling requests for data, and clearly provide all the necessary information to the users on how to actually place their request. It should be clearly explained on the public body’s website (and not hidden in a part of the website that is difficult to find) how the request has to be formulated and what information it should contain. This would not only show the user what he needs to do, but would also facilitate the process for the person or department managing the request. A possible manner of facilitating the requests is to provide a pre-defined web form guiding the users through the request and indicating the specific information that is required from them. Such a solution would allow for all the requests to be submitted in a uniform style, and clearly show the users what information is expected from them. This could also speed up the whole process and decrease the request processing time. As was already indicated before, it should be taken into account that some users may still have problems or questions with regard to ordering the
data they need, so the contact details of the data officer need to be clearly indicated in the request form.

4.1.4. Response Time

The provided information on the request procedure should also indicate the response time limits to requests. While much of the spatial data may be directly accessible through view or download services, a response time limit is still important in situations where access to the services requires a particular procedure to be followed (e.g. with registration and authentication requirements), or where the data are still delivered via another way, e.g. on DVD or a hard disk, etc. Hence, this section does not refer to the response times for the INSPIRE services as defined in the service level agreements or the performance requirements in the implementing rules on the network services, but rather to the time for the public body to clear the required authentication, authorisation and licensing procedures for gaining access to the service.

Obviously, any response time has to be in line with the applicable legal requirements. For instance, according to the Access directive, environmental information has to be delivered for access as soon as possible, with a maximum of 1 month after the request, and in case of high volume and complexity of the data maximum 2 months after the request has been made (art. 3.2 Access Directive). In case of re-use, article 4.2 of the PSI directive requires that the data are delivered within the same time limit as applies under the national access legislation, or within a reasonable time and maximum 20 working days in case there is no national access legislation. In case of extensive or complex requests the time limit can be extended to maximum 40 working days from the request. National access legislation may impose yet another set of maximum time limits that need to be obeyed. While maintaining these different time limits is sufficient to comply with the applicable legislation, the best way to facilitate the availability of spatial data is to apply the same time limit for all types of requests. A uniform time limit is an excellent way to promote user-friendly policies and minimize barriers to obtaining spatial data. For the benefit of the users, preference should be given to the shortest time limits proposed in the legislation. Such solution would set new, high quality standards and give an example to providers of other types of public sector data.

While it is important for users to know the theoretical response time, it is even more interesting for them to know the actual time needed by the public body to process their request. Transparency of the functioning of the public body could be enhanced considerably by the publication of the average response times on actual requests, of course with the caveat that this does not create any rights for the users beyond the legal obligations of the public body.
4.1.5. Means of Redress

Another type of information that should be provided to the users is the possible means of redress in case they would like to make a complaint about the way their request for spatial data has been treated. According to article 6 of the Access directive “any applicant who considers that his request for information has been ignored, wrongfully refused (whether in full or in part), inadequately answered or otherwise not dealt with in accordance with the provisions of [the directive], has access to a procedure in which the acts or omissions of the public authority concerned can be reconsidered by that or another public authority or reviewed administratively by an independent and impartial body established by law”. The PSI directive only refers indirectly to the need for appropriate means of redress in case of any complaints with regard to obtaining PSI, by stating in article 4.4 that “any negative decision shall contain a reference to the means of redress in case the applicant wishes to appeal the decision”, and in article 7 that the public bodies have to ensure that applicants “are informed of available means of redress relating to decisions or practices affecting them”. As a result of these provisions, the public body should inform the users about the possibility to question the public body’s decision regarding a request for data. Users should also be informed about which public authority, administrative body or court is responsible for the review procedure and about the manner in which the complaint should be made. This right given to the users to challenge decisions of the public body (or the lack of thereof) is a guarantee that any actions of a public body regarding their request are always performed in compliance with the existing legal regime. Of course, account should always be taken of the national regulations on freedom of information, which also include their own rules on review procedures.

4.1.6. Use conditions

Once the users have decided which spatial data are suitable for their purposes, they should of course also be made aware of the conditions for the use of these spatial data, so that they can determine whether they can actually be used in the way that is required to fulfil the purpose. Hence, a description of what exactly can be done with the spatial data can determine whether users actually decide to make a request for the data. The need for clear use conditions is confirmed in the European legislation. The preamble of the PSI Directive states that “ensuring that the conditions for re-use of public sector documents are clear and publicly available is a precondition for the development of a Community-wide information market. Therefore all applicable conditions for the re-use of the documents should be made clear to the potential re-users” (see recital 15 of the PSI directive). The INSPIRE Directive also requires providing information on “conditions applying to access to, and use of, spatial data sets and services and, where applicable, corresponding fees” in its article 5.2.
Depending on the requesting party and the purpose for which the data will be used, the conditions of use might differ. Therefore, the public body should clarify the specific conditions for each data set, for each type of use, and each manner of delivery. In the future, most data will most likely be delivered via services, such as the network services that have to be set up under INSPIRE. However, currently not all public bodies are ready to provide large amounts of data via services. In addition, some users may still prefer obtaining the spatial data on CD or DVD. At the same time, it should be remembered that “any applicable conditions for the re-use of documents shall be non-discriminatory for comparable categories of re-use”, as described in article 10 of the PSI Directive. Hence, the public body could introduce different categories of use to the extent permitted by law, if it feels this is necessary for achieving the objectives of its data policy for disseminating the spatial data. However, it is advised that the public bodies limit the number of categories, not only to enable the user to decide quickly which type of use he or she should apply for, but also to limit the administrative burden for their own departments. The less different types of use (and accompanying conditions) are introduced, the easier it will be for the public body to manage requests, as the procedure can be standardised and it will be simpler to assess and classify the request.

Common differentiations between types of users include public sector or private users, commercial or non-commercial users and science or education related users. However, if a public body does not require such distinctions, it is of course preferable that they are not unnecessarily introduced. In case different conditions do apply, it is necessary to provide a clear overview and explanation of these conditions to the users. The users should be able to easily find information on any allowed use of the data or any applicable restrictions, including e.g. only making a limited number of copies of the data, not disseminating the data to third parties, making added-value products, not making any publicity or advertising based on the spatial data that is obtained, etc. Only with such detailed information, the users will be able to decide whether they want to make a request to obtain particular spatial data.

Two elements should be considered here. First, the distinction between the types of use should be clearly indicated. Such distinctions may be based on the user (e.g. public body, private user, education or research institution), the use (internal use, use in paper or online publications, creation and sale of value-added products), or the purpose of the use (commercial use, non-commercial use, educational or research objectives, etc.). The scope of each category should be clearly defined. Second, whatever distinction is chosen, the conditions for the user to fall within one of the categories have to be clearly explained on the public body’s website, again with a reference to a possible contact point for more guidance. In choosing the categories, the public bodies should keep in mind that some categories are easier to define and leave less room for ‘grey areas’ than
others. For instance, the distinction between commercial and non-commercial use can cause many discussions. The two types of use could be distinguished based on the nature of the user, entailing that any use by a commercial company would be considered commercial. However, in this case one could wonder why internal use by a commercial company would be different from internal use by an NGO. Next, the distinction could also rely on the use rather than the user, implying that income will be raised and money will be made. However, this would entail that for instance NGOs selling their publications would also fall under commercial use. Hence, whether the division between commercial and non-commercial use is based on the organisation requesting the spatial data, or the activity that the data are being requested for, the public body should be aware of the consequences of the chosen division and make sure that it is clearly explained and that the possible areas of discussion remain as limited as possible.

4.1.7. Charges
Finally, the charges for using spatial data can also be an important factor for users to decide whether they want to file a request or not. Therefore, the public body’s data policy should include a clear pricing policy, in accordance with the existing legal framework at the European and national level. First, article 5.3 of the Access Directive requires that "where charges are made, public authorities shall publish and make available to applicants a schedule of such charges as well as information on the circumstances in which a charge may be levied or waived". Second, article 7 of the PSI Directive provides that "any applicable conditions and standard charges for the re-use of documents held by public sector bodies shall be pre-established and published, through electronic means where possible and appropriate. On request, the public sector body shall indicate the calculation basis for the published charge. The public sector body in question shall also indicate which factors will be taken into account in the calculation of charges for atypical cases". As was explained earlier, the EU directives also indicate the upper limits to the charges that can be made. These limits differ for access under the Access directive and the INSPIRE directive, re-use under the PSI directive, and sharing under the INSPIRE directive.

While the level of pricing and the choice of charging method are not discussed in this paper, some remarks can be made about the information that should be given to the potential users on the applicable charges and prices. Any documentation about the pricing policy should be easily accessible on the website of the public body in a clearly indicated section. This documentation should include for each dataset and each type of use: the pricing mechanisms and fees, the factors that are taken into account in the calculation process of the fees, and the charging foundations and methods. If exemptions or reductions of the fees are possible, this should also be indicated, including the manner in which they can be obtained. Ideally, the users should not only be informed about the pricing policy, but they should also be able to calculate, at least
approximately, the fee before requesting the data, e.g. by a price calculating tool that is offered on the website. Of course, it should be made clear that his price is only indicative, and may not be exactly the same as the actual price that will be charged (although the indicative price should not differ too much from the actual price). Ideally, the prices should not hold many different factors and involve complex calculations that could drive potential users away.

4.1.8. The Role of Metadata

Metadata is defined in article 3.6 of the INSPIRE directive as “information describing spatial data sets and spatial data services and making it possible to discover, inventory and use them”. The directive imposes an obligation to create metadata that are complete and of a quality sufficient to fulfil the designed purpose, and to keep these metadata up to date. This obligation was introduced in order to reduce transaction costs (see recital 15 of the INSPIRE directive). Metadata should contain information on the conformity of spatial data sets with the implementing rules on the interoperability of spatial data sets and services; the conditions applying to access to and use of spatial data sets and services; and, where applicable, corresponding fees; the quality and validity of spatial data sets; the public authorities responsible for the establishment, management, maintenance and distribution of spatial data sets and services; and limitations on public access and the reasons for such limitations (article 5.2 of the INSPIRE directive).

Ideally, the metadata should provide all the information mentioned in the data policy. With regard to the use conditions, the INSPIRE regulation of metadata imposes the use of the metadata element Conditions applying to access and use, in the ISO standard on metadata referred to as use limitations (European Commission, 2008) This is a free text element, which should allow data providers to briefly describe the terms and conditions for the use of spatial data and the charges. Additionally, the purposes for which the data are not suitable can be listed there, and a link to the use conditions of the data provider. In many cases, it may not be possible to describe the conditions in the metadata element, because more information is needed than can be made available in the limited space foreseen by or suitable for the metadata fields. Hence, while the metadata should hold information on e.g. the use conditions for the spatial data, they may not be able to reflect all documentation the user needs to make his decision on whether he or she can use the data for his intended purpose or not. For instance, it will be impossible for the public body to describe in the metadata all conditions and charges that apply for all possible types of use that it allows. Therefore, it is advised that the metadata only hold a link to the webpage of the public body where all conditions are set out as indicated earlier (see also DT on Data and Service Sharing, 2010). Of course, it will be important for the public body to ensure that, if the URL of this webpage changes, the metadata are adapted accordingly.
4.1.9. **Code of Practice Checklist**

The following table provides a summary or 'checklist' of the main elements of the Code of Practice.

**Table 3: Checklist of the Main Elements of the Code of Practice**

<table>
<thead>
<tr>
<th>Checklist</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Basic information</strong></td>
<td></td>
</tr>
<tr>
<td>• Provide basic information about your organization on the website</td>
<td></td>
</tr>
<tr>
<td><strong>2. Practical Arrangements (article 3.5 Access directive, 9 PSI directive)</strong></td>
<td></td>
</tr>
<tr>
<td>• Provide access to registers, lists or assets lists on the website</td>
<td></td>
</tr>
<tr>
<td>• Make metadata available online in line with the INSPIRE implementing rules</td>
<td></td>
</tr>
<tr>
<td>• Indicate access restrictions or use conditions in the metadata or provide a link to additional information</td>
<td></td>
</tr>
<tr>
<td><strong>3. Request procedure (article 3.2, 4.5, 6 Access directive, 4.2, 4.3, 4.4, 7 PSI directive)</strong></td>
<td></td>
</tr>
<tr>
<td>• Develop a request procedure and make it available online</td>
<td></td>
</tr>
<tr>
<td>• Specify differences e.g. between types of users or conditions for re-use</td>
<td></td>
</tr>
<tr>
<td>• Specify how the request should be formulated and what information it should contain</td>
<td></td>
</tr>
<tr>
<td>• Provide a web form to send requests</td>
<td></td>
</tr>
<tr>
<td>• If users have to register, ensure that personal data is stored in compliance with the national data protection regulations</td>
<td></td>
</tr>
<tr>
<td>• Specify delivery methods</td>
<td></td>
</tr>
<tr>
<td>• Specify time limits within which a request will be answered</td>
<td></td>
</tr>
<tr>
<td>• Provide information about available means of redress</td>
<td></td>
</tr>
<tr>
<td>• Provide information about payment methods</td>
<td></td>
</tr>
<tr>
<td><strong>4. Information officer/ Contact point/ Request for additional information (article 3.5(a), (c) Access directive, 9 PSI directive)</strong></td>
<td></td>
</tr>
<tr>
<td>• Assign a contact person/ data policy officer to handle requests for support</td>
<td></td>
</tr>
<tr>
<td><strong>5. Available data and conditions (article 8 PSI directive, 5, 14.3, 14.4, 17.3 INSPIRE directive)</strong></td>
<td></td>
</tr>
<tr>
<td>• Specify conditions for all types of available data, all types of re-use, all types of users and services</td>
<td></td>
</tr>
<tr>
<td>• Inform users about their obligations (e.g. attribution, error reporting)</td>
<td></td>
</tr>
<tr>
<td>• Make licensing information available online</td>
<td></td>
</tr>
<tr>
<td>• Use disclaimers or click-use licenses when possible, and make the full version of the licence available to the users (via a link or in a PDF document delivered via email)</td>
<td></td>
</tr>
<tr>
<td>• Make detailed information available about the availability of services and the conditions for their use</td>
<td></td>
</tr>
<tr>
<td>• Refer to the conditions and limitations in the metadata</td>
<td></td>
</tr>
</tbody>
</table>
4.2. Standard licences

Another important element in improving accessibility of spatial data, next to the data policy, is the use of standard licences, preferably made available on the public body’s website. Such licences provide greater transparency to the users and allow them to assess their contractual rights and obligations before entering into an agreement with the public body.

The harmonisation of licensing conditions and the use of the same model licences by many public bodies, either within a Member State or across Member States within a particular sector, would be beneficial for users wanting to obtain and combine datasets from several public bodies. This is also recognised by the
PSI directive, which obliges Member States in which licences are used, to ensure that standard licences are available, which can be adapted to meet particular licence applications (article 8.2 PSI directive). The project’s Code of Practice focused on model licences to be used by the Surveys for providing their geological spatial data to the users. While these licences can be applied for other types of data, one should also recognise their limited scope and objectives.

For the design of the model licences, the OneGeology-Europe project used existing licensing models and adapted these to the needs of the Geological Surveys and the requirements of the EU legal framework for the availability of public sector spatial data. Licences that were examined included Creative Commons, the Ordnance Survey open data licence, the INSPIRE model licences and a number of national developments such as the Dutch Geo-gedeeld licensing suite.

In order to avoid ‘reinventing the wheel’, we combined concepts of the different licences to suit our particular needs. Two model licences were proposed (Kuczerawy et al., 2010). The Basic OneGeology-Europe licence is meant for data that is available free of charge and with minimal use conditions or restrictions. It can be used as a click-licence or in the form of general conditions listed on the website that do not require the signing of a contract. This licence is mostly based on the Ordnance Survey Open Data Licence, and the INSPIRE basic licence. It is a worldwide, royalty-free, non-exclusive licence to use the data for any purpose, free of charge. The user has to include a standard acknowledgement of the rights of the data provider in any use, and he or she should avoid any misrepresentation or suggestion of endorsement by the data provider.

Next, the Specific OneGeology-Europe licence was designed for data available under a charging regime and under more restrictive conditions. The main section of the licence deals with the allowed use. This section provides different options and standard terms for e.g. Web Mapping Services, Web Feature Services and other forms of access; and for different types of users (public administrations, type of entities). No distinction is made between e.g. commercial and non-commercial use, but rather between the different activities that can be performed based on the spatial data that are obtained (e.g. making copies, publication, creating derivative products, etc.). The sections on charges and the delivery process also take into account different options, such as the delivery via download services, DVD or ftp. Additional clauses of the licence deal with warranties, liability, conflict resolution, and the termination of the licence (see http://www.law.kuleuven.be/icri/deliverables/2071G-E_WP7_D7.pdf?where=).

The next table provides an overview of the main sections of the basic and specific OneGeology-Europe licence.
Table 4: Comparison of Basic and Specific OneGeology-Europe Licences

<table>
<thead>
<tr>
<th>Basic OneGeology-Europe licence</th>
<th>Specific OneGeology-Europe Licence</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Worldwide, royalty-free, non-exclusive licence</td>
<td>• Non-exclusive, non-transferable licence</td>
</tr>
<tr>
<td>• Any use allowed</td>
<td>• Allowed use</td>
</tr>
<tr>
<td>• Free of charge</td>
<td>• WMS: display, navigate, zoom in/out, an or overlay datasets, display legend information and metadata</td>
</tr>
<tr>
<td>• Attribution (optional: require attribution in sub-licence)</td>
<td>• WFS</td>
</tr>
<tr>
<td>• No misrepresentation or suggesting endorsement</td>
<td>o Conditions for public administration users</td>
</tr>
<tr>
<td>• Delivery method</td>
<td>o Conditions for private users</td>
</tr>
<tr>
<td>• No warranty</td>
<td>• Charges</td>
</tr>
<tr>
<td>• Applicable law</td>
<td>o Free of charge</td>
</tr>
<tr>
<td>• Possible changes to the licence</td>
<td>o Description of details of charges, timing of payment and payment arrangements</td>
</tr>
<tr>
<td></td>
<td>• Attribution</td>
</tr>
<tr>
<td></td>
<td>• No unauthorised use</td>
</tr>
<tr>
<td></td>
<td>• Security measures</td>
</tr>
<tr>
<td></td>
<td>• Delivery method</td>
</tr>
<tr>
<td></td>
<td>• Liability waiver</td>
</tr>
<tr>
<td></td>
<td>• Force majeure</td>
</tr>
<tr>
<td></td>
<td>• Applicable law</td>
</tr>
<tr>
<td></td>
<td>• Processing of personal data</td>
</tr>
<tr>
<td></td>
<td>• Assignment, sub-licensing and contracting</td>
</tr>
<tr>
<td></td>
<td>• Contact persons</td>
</tr>
<tr>
<td></td>
<td>• Conflict resolution</td>
</tr>
<tr>
<td></td>
<td>• Termination</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS AND WAY FORWARD

The OneGeology-Europe Code of Practice and model licences tried to increase the harmonization of the licensing practices of the Geological Surveys in the project, based on the different policies and practices that were found in these organizations. While the Code of Practice made a number of recommendations to synchronize the data policies of the Surveys and to ensure compliance with the requirements from the PSI directive, the Access directive and the INSPIRE directive, the model licences still gave them the option to maintain some of their existing practices for disseminating data. In this way, the project’s objective of facilitating access and use of geological spatial data could be reached, without asking the public bodies to change their data sharing cultures too aggressively within the short time span of the project. As in many of the organizations the data
However, some additional remarks should be made for any further research and practice towards harmonizing data policies and licences. First, as was found in the OneGeology-Europe project, in the search for standard licences, the variety of business models of the public bodies providing spatial data cannot be overlooked. This is one of the major factors that hinder the harmonization of the licensing methods across Europe. One of the reasons for this is a dissimilar ability to deliver the data for free, which is mostly dependent on the financing of the public body. Thus any data policy and associated model licences have to take into account these differences. They consequently have to cover situations when spatial data are made available free of charge and without many restrictions on the use, but also situations when data are charged for and the conditions are much more restrictive. This means that a one-size-fits-all solution is not going to be sufficient. In order to be able to fulfil all the needs of the public bodies providing spatial data, multiple model licences must be designed allowing for flexible solutions for each public body using them. The range of situations that have to be covered suggests that a few standard licences might be necessary to satisfy all the licensing needs of the organizations providing data. At least two model licences seem required, one for the free of charge provision of data with minimal restrictions on the use, and a second one for spatial data for which a fee is charged and the conditions of use are more restrictive.

In addition, for each organisation that feels that its particular type of data or data policy would not fit into the limited number of model licences proposed and that it needs a separate set of conditions or licence model, it should critically assess whether this is actually the case. In many cases, such a separate policy might not be necessary, because the reasons behind the need of the public body for specific conditions or requirements are the same, but just understood or formulated differently. In many cases, their concerns might already be taken into account in the limited number of licences that are proposed. Raising the awareness among public bodies about the requirements and consequences of different information policies could also, by indicating the lack of need for ever differing approaches, limit the number of initiatives being taken for creating new licensing models next to the many existing ones. In this way, the harmonisation of information policies and licensing models across sectors and countries could be greatly facilitated. However, this requires more research into two aspects: first, to what extent information policies and licensing models can be harmonised while still complying with all national and international legal provisions and
requirements; and second, how the public bodies’ culture and approach to dissemination of data can be changed from each public body designing its own specific conditions for data dissemination to all public bodies adopting a limited number of general policies and practices for making spatial (and other public sector) data available.

REFERENCES


GEO SHARED LICENSES: A BASE FOR BETTER ACCESS TO PUBLIC SECTOR GEO-INFORMATION FOR VALUE ADDED RESELLERS IN EUROPE

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Abstract
In a digital age public sector geoinformation (PSGI) is potentially a vital link in the added-value chain. Yet private sector value-added resellers (VARs) still face a number of barriers to using PSGI. Price is only one impediment. The complexity of licences and restrictive licence conditions of PSGI may be an even bigger obstacle. Especially when combining different datasets, VARs can face a quagmire of conflicting licence conditions. Batty (2006 Environment and Planning B: Planning and Design 33 163 – 164) called for research that would stimulate value-added use of PSGI. However, inconsistent and intransparent licence conditions for PSGI are among the biggest obstacles of PSGI for VARs. This paper explores the current PSGI licences to assess the actual restrictions and how current obstacles can be levelled. The Creative Commons licensing concept was explored and adapted to make it suitable for licensing PSGI. The resulting concept of Geo Shared licences is a means to harmonise licence conditions for PSGI. Our research shows that the Geo Shared concept can be a valuable contribution to further harmonisation of PSGI licences and thus development of value-added chains. Furthermore, development of geographic information infrastructures will also be stimulated. Similarly, the concept can be considered as a serious option within the Infrastructure of Spatial Information for Europe (INSPIRE), as a way towards transparent harmonised licences in Europe and beyond.

Keywords: Creative Commons; licences; geographic information infrastructure; INSPIRE; reuse of public sector information: Geo Shared.

1 GEOGRAPHIC INFORMATION INFRASTRUCTURE DEVELOPMENT

1.1 FRAMEWORK

The terms 'geographic information', 'geographic data', 'spatial information' and 'spatial data' are interchangeably used as synonyms. For the purpose of this article only the term geographic information (GI) will be used. Access to GI is of vital importance to the economic and social development of the nation. Nations around the world are developing geographic information infrastructures (GIIs), also referred to as spatial data infrastructures (SDIs), with access to GI at the core. For more advanced GIIs (re)use is considered to be the driver of a GII. In this respect special reference is made to value added use of available basic or framework GI. Most GI belongs to public sector bodies with access and use governed by specific access policies. In Europe many public sector bodies use licence fees to finance their operations and to guarantee certain levels of GI quality. However, each body applies different licence conditions and pricing structures. It is this inconsistency and intransparency that forms one of the biggest obstacles for value-added re-users (VARs) in their decision to (re)use public sector geographic information (PSGI) for their activities (see Groot et al., 2007; RAVI 2000; STIA 2001; van Loenen et al., 2007). As a consequence, value-added use, the driver for advanced GIIs, remains limited.

A GII or SDI may be defined as the framework to facilitate the management of information assets, with a focus on better communication channels for the community for sharing and using data assets, instead of aiming toward the linkage of available databases (Rajabifard et al., 2002). Governments have an important role in the development of GIIs. They are often both providers and users of GI, and most often government agencies lead GII development. This is especially true when the government is the main provider of GI. They can decide what information is collected and maintained and, through its access policies, they also determine the extent to which a dataset can be used. Pricing of PSGI is an important factor for users in their decision to use a data set for value-adding. However, surveys held in 2007 and 2008 among VARs in Europe suggests that the most prominent barriers for value-added (re)use are the complexity, inconsistency, intransparency and restrictive use conditions (Groot et al., 2007; MICUS, 2008a);. The European Directive on the reuse of public sector information 2003/98/EC, the so-called PSI Directive, is explicitly directed at promoting value-added use of PSI (EC 2003). However, it only prescribes a
minimum of harmonisation for licenses, keeping the hindering status quo alive. Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community – the so-called INSPIRE Directive – requires Member States to exchange, share, access and use interoperable spatial data and spatial data services across the various levels of public authority and across different sectors. INSPIRE should assist policy-making in relation to policies and activities that may have a direct or indirect impact on the environment. However, while INSPIRE requires data to be shared between public sector bodies, it also allows public sector bodies to charge for (re)using the data by leaving the regime of the PSI Directive unaffected. So far, these Directives have not resulted in a harmonisation of license conditions leaving value-added use of PSGI hindered as before. INSPIRE must be transposed into national legislation by 15 May, 2009. A harmonised licensing framework has been developed by the INSPIRE Data and Service Sharing Drafting Team. However, this framework will be voluntary.

1.2 USERS AND THEIR NEEDS

Users of the GII "will probably be the most mentioned group and yet actually the least considered" (McLaughlin and Nichols, 1994, p.72). Van Loenen (2006) distinguishes four user groups:

1. primary users (the collector and major users);
2. secondary users (incidental users for similar purposes as the primary user);
3. tertiary users (users that use the dataset for purposes other than those for which the information was collected and the dataset created), and
4. end-users.

Primary users are those that use the dataset for the initial purpose of information collection on a continuous basis. They typically belong to the organisation that has collected and processed the information. Secondary users use the information incidentally for similar purposes, and tertiary users are those that add value to the framework dataset by using the data set for other purposes then the collection purpose. Finally, the end users are the fourth group of users. This group consists of citizens, decision makers, and others that use the end product of geographic information –for example, a map or an answer to a query – mostly through services provided by the tertiary users. Although secondary, tertiary and end users all may reuse PSGI, it is the tertiary user that by definition reuses PSGI for value adding. Therefore, this paper’s primary focus is on the tertiary user.

Users require transparency of the information policies (eg Groot et al, 2007; RAVI, 2000) and require consistency in the access policies throughout government (KPMG, 2001; PIRA International, 2000; QSIO, 2006; RAVI, 2000; STIA, 2001). Differences in pricing, use restrictions, and liability regimes may result in confusion and ultimately limited use of the dataset (Meixner and Frank, 1997). The user is, for example, uncertain about the cost he or she should calculate for complete jurisdiction coverage. A consistent or harmonised access policy throughout government may promote the use of framework information. In this paper we assess the extent to which the concept of the Creative Commons (CC) can be used as a tool to develop a model that will harmonise current PSGI licences.

1.3 READING GUIDE

First, we will consider attempts to standardise licences in general, with a focus on CC. In section 3 we describe the present situation with regard to the use of licences in the Netherlands, Norway, Germany, and England. In section 4 we look at the pros and cons of applying CC for geographic information and look at the issues that remain when aiming at the extended use of CC. In section 5 we introduce the Geo Shared concept as an alternative framework. We conclude with an analysis. Further, we will discuss the issues that CC can and cannot solve with regard to access to PSGI for VARs.
2 STANDARDISING LICENSES

2.1 INFORMATION LICENSES

Access to and (re)use of geographic information is often regulated by licences to allow the information holder to economically or otherwise exploit the information. A licence is a contract imposing express limits on the use of the data (Dreyfuss, 1999). One can generally redistribute a licenced copy only if especially contracted for the right to do this (Samuelson, 1998). Other legislation such as privacy legislation may impose restrictions as well. Intellectual property rights (IPR) can be considered a prerequisite for successfully exploiting information.

2.1.1 Copyright and Database Rights

Intellectual property rights such as copyright, and in Europe also database rights, may be had in many types of geographic information, such as topographic information. Copyright gives the creator of an original work exclusive rights to it (eg right to publish, distribute, and adapt), most often for a limited time, usually in the order of seventy years after the death of the author. The primary objective of copyright is to promote creativity and innovation 1. It assures authors the right to their original expression, but encourages others to build freely upon the ideas and information conveyed by a work (Onsrud and Lopez, 1998). Copyright protection extends to expressions and not to ideas, procedures, methods of operation, or mathematical concepts as such (WIPO, 1996). Differences among the copyright laws of various nations have resulted from a wide range of interpretations that nations have developed for the concept of originality (Onsrud and Lopez, 1998).

The EU Directive on the legal protection of databases (96/9/EC), the so-called Database Directive, made a significant change to intellectual property rights in Europe. This directive created a 'new' sui generis 2 right for the creators of databases that do not qualify for copyright as such. While copyright protects the creativity of an author, database rights protect the substantial investments in obtaining, verification, or presentation made by the producers. Under the terms of the Database Directive the rightholder may prohibit the extraction and/or reuse of the whole or a substantial part of the database. Database rights last for fifteen years from the end of the year that the database was made available to the public. Any substantial changes, which could be considered to be a substantial new investment, will extend the protection for another fifteen years. Therefore, databases that are regularly updated could effectively have a perpetual protection. Database rights may be reserved only if the investments in obtaining, verifying or presenting the data are made as a main commercial activity of the database producer. If a database is created without substantial investments or as a by-product of another activity, the so-called spin-off doctrine applies (Hugenholtz, 2005). The European Court handed down a number of rulings in 2004 confirming the spin-off doctrine 3. On April 2009 the Council of State, the highest Dutch Court of Appeal for Administrative Law, upheld 4 the District Court of Amsterdam's 5 ruling that a public sector may not claim database rights for public sector databases, if the database was created as part of its public task and was funded by taxpayers’ money. Thus, the spin-off

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2 The literal meaning of sui generis is of its own kind. In law it is a term used to identify a legal classification that exists independently of other categorisations because of its uniqueness or owing to the specific creation of an entitlement or obligation.
3 See for instance, The British Horseracing Board Ltd and Others v. William Hill Organization Ltd. ECJ, joint cases C-46/02, C-338/02 and C-442/02, 9 November 2004.
4 Raad van State case nr. 200801985/1. The Council of State reiterated in its ruling that databases funded by public money and produced for a public task rather than specifically for commercial purposes, cannot be protected by database rights as the investments made to produce the database—even though the investments were vast—had not carried a substantial risk.
5 Landmark Nederland BV v. Municipality of Amsterdam, Amsterdam District Court reg. nr. LJN BG1554, 11 February 2008.
doctrine has a significant bearing on public sector bodies claiming database rights as there may be no legal basis if they are publicly funded.

2.1.2 Some Rights Reserved Licenses

In the 1990s changes were made to United States Copyright Act in order to offer better protection of works in a digital environment. These changes included retroactively extended copyright terms, thereby threatening to prevent the so-called orphaned works from being published on the Internet\(^6\). As a reaction to these copyright changes, several organisations were founded to provide alternative licensing systems, on the basis of a ‘some rights reserved’ approach. The terms ‘some rights reserved’ is used to denote a concept somewhere in between the ‘all rights reserved’ approach of the Copyright Act and the ‘no rights reserved’ approach of the Public Domain.

There are now over 60 ‘some rights reserved’ type licences currently recognised by the Open Source Initiative. The most popular types currently in use for small group or individual users for non-software works are Creative Commons (CC) licences and variations of the GNU Free Documentation Licence (FDL). Although the latter was designed originally to apply to software manual documentation, it has been applied far more widely – for example, for projects of the Wikimedia Foundation (Onsrud, 2006). The fact that there are so many different ‘some rights reserved’-type licences is a fair illustration that attempts to standardise these have not succeeded, as illustrated by the attempts of the Science Commons to develop a licence framework since 2005. Even to enable just one transaction, namely the transfer of biological materials, Science Commons have developed four different Material Transfer Agreements (http://www.sciencecommons.org/projects/licensing/).

In the US the National Research Council (NRC) suggests that, in order to facilitate finding and (re)using geoinformation, a national GI marketplace should be set up. The would-be customer could search for GI and buy the suitable data after ‘clicking-through’ to the appropriate server. In more advanced implementations, the seller or licensor might define for each dataset or group of datasets a pricing formula that varies with differing standard license or sale conditions (National Research Council, 2004).

2.2 Creative Commons

CC was founded in 2001 as a nonprofit organisation to offer flexible copyright licences for creative works such as text articles, music, and graphics. They advocate a system whereby works can be made available through the Internet without forfeiting their intellectual property rights. To facilitate this, they have developed a licensing system, the co-called CC licences. Thus, works can be made easily accessible for dissemination or for reuse. As at February 2009, fifty countries around the world have set up national CC organisations and have transposed the US version of CC licences into national legislation. CC licences are becoming very popular; at the end of 2003 there were worldwide about 1 million CC licences in use, and at the end of 2008 this number has exploded to 130 million and at the time of writing is still growing exponentially (www.creativecommons.org). Within Open Geospatial Consortium efforts to arrive at a geospatial rights management standard, variations of CC licences are also considered (Vowles et al., 2007).

CC licences try to find a balance between the ‘all rights reserved’ concept of traditional IPR and the ‘no rights reserved’ concept of the public domain, by employing a ‘some rights reserved’ approach. Through their website (http://www.creativecommons.org) they offer six standard licences for anyone wanting to publicise their work. Each CC licence contains the following standard clauses:

1. The licence applies worldwide.
2. The licence is irrevocable.
3. The licence is granted for the term of the appropriate IPR legislation.
4. Licensors do not forfeit their IPR.
5. Acknowledgement of the source is compulsory (attribution the way the author requests).

Licensees must seek permission for actions that are not allowed by that specific licence.

Each copy of the work must contain a link to the licence.

Licensees may not alter the terms of the licence agreement.

Licensees may not employ technology or other means to limit access to the work in a way that is contradictory with the terms of the licence agreement.

Works are offered on an 'as-is' basis without any guarantees and the licensor does not accept any liability claims.

Apart from each of these standard clauses, the six CC licences offer one or more of the following terms:

1. You let others to distribute derivative works only under a license identical to the license that governs your work (share alike).
2. You let others copy, distribute, display, and perform only verbatim copies of your work, not derivative works based upon it (no derivative works).
3. Others may copy, distribute, display and perform your work – and derivative products based upon it – but for non-commercial purposes only (noncommercial);

The six main licences are described in Table 1.

<table>
<thead>
<tr>
<th>Licence type</th>
<th>Icons</th>
<th>Licence conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribution (by)</td>
<td><img src="image1" alt="Icon" /></td>
<td>This license lets others distribute, remix, tweak, and build upon your work, even commercially, as long as they credit you for the original creation. This is the most accommodating of licenses offered, in terms of what others can do with your works licensed under Attribution.</td>
</tr>
<tr>
<td>Attribution Share Alike (by-sa)</td>
<td><img src="image2" alt="Icon" /></td>
<td>This license lets others distribute, remix, tweak, and build upon your work, even for commercial reasons, as long as they credit you and license their new creation under the identical terms. This license is often compared with open source software. All new works based on yours will carry the same licence, so any derivatives will also allow commercial use.</td>
</tr>
<tr>
<td>Attribution No Derivatives (by-nd)</td>
<td><img src="image3" alt="Icon" /></td>
<td>This license allows for redistribution, commercial and noncommercial, as long as it is passed along unchanged and in whole, with credit to you.</td>
</tr>
<tr>
<td>Attribution Non-Commercial (by-nc)</td>
<td><img src="image4" alt="Icon" /></td>
<td>This license lets others remix, tweak, and build upon your work noncommercially, and although their new works must also acknowledge you and be noncommercial, they don’t have to license their derivative works on the same terms.</td>
</tr>
<tr>
<td>Attribution Non-Commercial Share Alike (by-nc-sa)</td>
<td><img src="image5" alt="Icon" /></td>
<td>This license lets others remix, tweak, and build upon your work noncommercially, as long as they credit you and license their new creations under the identical terms. Others can download and redistribute your work just like the by-nc-nd licence, but they can also translate, make remixes, and produce new stories based on your work. All new work based on yours will carry the same licence, so any derivatives will also be noncommercial in nature.</td>
</tr>
<tr>
<td>Attribution Non-Commercial No Derivatives (by-nc-nd)</td>
<td><img src="image6" alt="Icon" /></td>
<td>This licence is the most restrictive of the six main licenses, allowing redistribution. This licence is often called the ‘free advertising’ licence because it allows others to download your works and share them with others as long as they mention you and link back to you, but they can’t change them in any way or use them commercially.</td>
</tr>
</tbody>
</table>
Each of the CC licences generates three versions of the same licence agreement. The first version – a commons deed in plain language suitable for laymen – is a summary of the licence complete with the relevant symbols as displayed in Table 1. The second version – a legal code – is the actual licence and is legally binding. The legal code is suitable for lawyers and consists of a number of pages in legal terminology. The third version – a digital code – is a machine-readable translation of the licence that helps computer programs such as search engines to identify the work by its terms of use.

CC aims to promote access to IPR protected works as an open content organisation. Open access works, while copyrighted, allow use without obtaining prior permission since a general licence is granted ahead of any specific use. A basic condition of a CC licence is that user rights are supplied without royalties, although the right to receive a reward is not forfeited under a CC licence. The licences were designed to suit creators who want to distribute their work independently to gain publicity or to build up a reputation, or to suit creators or organisations that act out of ideological or nonprofit objectives. The CC-licences are also applied to digital works to stimulate sales of the printed version of the same work, or to promote the use of paid support services (Boyle, 2007; National Research Council, 2004). CC-licences appear to be suitable for those that do provide their data for free such as nonprofit organisations, academia, and government organisations, but also suitable for VARs that may use the data as the trigger to generate revenue from the sales of related products or services.

3 PSGI LICENCES IN EUROPE

Although all EU Member States have to abide by the PSI Directive, there are still quite some differences with respect to access and user licences. Information regarding the Netherlands, Norway, North Rhine Westphalia (Germany), and England and Wales (United Kingdom) was collected as part of a study (van Loenen et al., 2007). In this chapter we will give a brief summary of access policies of these countries.

3.1 THE NETHERLANDS

In the Netherlands access to PSI and reuse of PSI are both regulated by the Freedom of Information Act (Wet openbaarheid van bestuur, known as the Wob). The Wob states that, with respect to access, fees should not exceed dissemination costs as far as possible. However, for reuse of PSI subject to IPR, charges should not exceed the total costs of collecting, producing, reproducing and disseminating documents, together with a reasonable return on investment. Some public sector organisations have their own specific legislation setting their own framework for disseminating information – for example, the Cadastre Act and the Meteorological Institute Act. At ministerial level there is a framework of policies and guidelines recommending that information should be made available to other national public sector organisations for dissemination costs. However, this framework does not apply to regional and municipal organisations (yet). The Wob is currently under review and the differences in pricing regimes will probably be amended.

In 2006, current licence agreements for PSGI were reviewed (Welle Donker, 2006). Licence terms and conditions appeared to be very diversely formulated, ranging from a few paragraphs written in plain language to countless pages written in legal language that is hard to understand for a layperson. The licence fees also vary significantly, ranging from free to hundreds of thousands of Euros for a complete dataset. Sometimes a differentiation is made between different types of users – that is, libraries, schools, universities and research institutes will pay lower fees than the private sector. Almost all of the licence agreements usually specify that the data are to be used only for internal purposes and if the dataset is to be used for any other purposes a separate licence agreement will have to be negotiated. In some cases one has to indicate what the data will be used for before access or permission for reuse is granted. Sometimes the dataset has to be returned after a (predetermined) goal has been attained. Sometimes one has to purchase an entire dataset and sometimes one gets access through a web service. None of the licence agreements contain provisions for the combined use of data from more than one source (Welle Donker, 2006). Formally no
differentiation is made between public sector users and non-public sector users. In practice, some public sector organisations have data-for-data agreements, in which they share data to create and maintain large-scale datasets. Some public sector organisations charge fees to other public sector organisations.

In spite of all these differences, all these licence agreements also show a lot of similarities as far as the main provisions are concerned. These similar provisions are:

- A non-exclusive user right is granted.
- Intellectual property remains with the supplier.
- The data may not be transferred to a third party without prior consent of the rightholder.
- Derivative products obtained by adaptation of the data (if allowed) must be clearly credited with the original source (name of supplier and year of acquisition).
- The supplier of the data indemnifies himself or herself against any claims to the comprehensiveness and accuracy of the data or any damage resulting from use of the data.
- General (nonspecific) financial provisions related to terms of payment.

3.2 Norway

Within the public sector several organisations handle geographic information. The Norwegian Mapping and Cadastre Authority (SK) –which falls under the Ministry of Environment– is responsible for the coordination of the Norwegian GII. In 2003 a white paper authorised GI sharing within the public sector by setting up a GII. This program, called Norge Digitalt (Digital Norway), provides not only a portal but also a framework for cooperation within the public sector. Nearly all state departments and agencies as well as local governments and some private partners have joined or are in the process of joining Norge Digitalt (ND). After paying a contribution, the government organisation then makes its GI available free of charge to other participating organisations. This way all participants can use free GI for its own internal processes. More than thirty state and almost all local government organisations are a member of ND. In Norway thematic GI should be available –often online– free of charge for everybody to view. For environmental information this has been the case by law since 1993.

If the private sector wants to use PSGI, they can buy datasets from a government-owned intermediary, the Norsk Eiendominformasjon (NE). NE acts as a one-stop shop for VARs to get the data and resell them to end users. A contract is drafted with the NE and NE pays royalties to ND. NE uses the same (restrictive) licence conditions for all information it resells. However, there are some unresolved issues with this system. SK is not allowed to sell information directly to third parties but other members of ND are. Several public sector organisations provide this information for free through web mapping services. Until 1 January 2007 all SK services were available freely on the web. To be in line with the access policy from the 2003 white paper, SK had to limit free access to ND partners only. NE does not have a publicly known pricing policy. NE is supposed to operate as a wholesale distributor but NE is also selling PSGI to end users thus blurring the boundaries between public and private tasks (Welle Donker and Zevenbergen, 2007).

3.3 North Rhine Westphalia (Germany)

North Rhine Westphalia (NRW) is one of the sixteen states of the federal republic of Germany. Each German state is responsible for its own topographic service and land register, environmental and statistical information collection, and in general for information policies. Information collection is largely decentralised and carried out mostly on the regional and local level. The different states have issued laws ("surveying and cadastral acts") that regulate both the work, and the authorities of the surveying and mapping agencies.

All local governments in NRW claim copyright and database right in their information. In NRW users of PSGI are granted a 'limited use right' as described in the Copyright Act and further in the Cadastre Act. Only with permission of the concerned organisation can information from local government be multiplied, made public, or provided to third parties. Making copies and processing the (digital) information for internal use are permitted.
The Cadastre Act rules that access to PSGI within government is without cost. The free access provision does not apply to access for VARs. One has to pay a fee according to the fee ordinance if cadastre information is used for commercial purposes. The fee for the information depends on the category of the layers, the information density, the size of the area requested, and the format requested (analogue, vector, raster). Further, there are different fees for different users. Although the fee ordinance provides the legal framework for the price setting of PSGI, it is generally regarded as complex and difficult to understand, and too inflexible to be of use for Internet applications. As in the Netherlands, VARs in NRW find the current restrictive licence conditions a major obstacle to reusing PSGI (MICUS, 2008b).

3.4 ENGLAND AND WALES (UNITED KINGDOM)

Within the UK, Scotland and Northern Ireland have devolved responsibilities. In England and Wales policy is set by the UK government. Therefore, we will limit ourselves to England and Wales. Local governments are responsible mainly for local planning and everyday operations of their areas. The UK has different copyright regimes that apply to GI. The main copyright law affecting PSGI is the Crown Copyright. Crown Copyright applies to PSGI produced by central government agencies referred to as Crown Bodies. However, it is not always easy to distinguish which public sector organisations are Crown Bodies and thus affected by Crown Copyright because of technical legal reasons (APPSI, 2004). Therefore, different central government agencies will have different copyright regimes regulating their information, resulting in different rules for reuse.

Most PSGI is generated by the Ordnance Survey (OS). PSGI is also provided by central government parties like the United Kingdom Hydrographic Office (UKHO), Her Majesty Land Registry (HMLR) and the Royal Mail Group. The local authorities of the UK (approximately 500, excluding the local authorities of London) have an agreement with public and private GI producers for the provision of GI products and services they require for performing their activities. This agreement is known as the Mapping Services Agreement (MSA). This competitive procurement results in the responsibility for the provision of GI to local authorities falling into the hands of three GI suppliers. In the MSA the OS is still the main provider of GI datasets with supporting datasets being provided by Intermap and Intelligent Addressing. However, the majority of the more widely used GI in the UK is derived from or is actually OS datasets. OS, UKHO and HMLR are all classified as trading funds and are required to generate a surplus. Therefore, these agencies all use restrictive licence conditions and fees to make their datasets available for reuse. Hence, access to these datasets will be governed by the underlining policies of these trading funds.

Like the Netherlands, the UK has no single access policy for PSI. As far as reuse within the public sector is concerned, OS uses a system of Collective Licensing Agreements (CLAs). A CLA is an agreement between the OS and a group of public sector organisations which allow the public sector organisations access to OS information for internal processes. As far as reuse by the private sector is concerned, UKHO uses a network of VARs which reuse hydrographic information on a royalty basis. OS also have licence agreements with various VARs on a royalty basis and/or upfront fees.

From the above examples we can see that there are vastly different approaches to PSGI licensing in Europe.

4 APPLYING CREATIVE COMMONS TO PSGI LICENCES IN EUROPE

Although CC licences appear vastly different from the PSGI licences currently in use, the general terms of most licence agreements do not differ that much from the CC licences. Thus, CC offers a promising access model. However, not all the available CC-licences can be applied to geographic information as such, especially if our aim is to make datasets available as input for commercial value-added products and services. Table 2 shows that there are some inherent problems when applying CC licences to PSGI for VARs. In this section we will discuss some of these concerns.
4.1 Matches and differences between PSGI licences and Creative Commons licences

As we have shown, there are matches and differences between current PSGI-licences and CC-licences. These are listed in tables 2(a) and 2(b) respectively. Light grey indicates a match, medium gray a near-match and dark gray a substantial difference.

**Table 2(a): Matches in licence conditions CC and European case studies**

<table>
<thead>
<tr>
<th>CC</th>
<th>NL</th>
<th>Norway</th>
<th>NRW</th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation of the information is in some cases allowed. Derivatives must be clearly attributed to the creator(s) of the original source.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Information is accessible on-line after the licence terms have been agreed to</td>
<td>Sometimes</td>
<td>Yes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>The intellectual property rights remain with the right holder</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>The user obtains a non-exclusive user right</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 2(b): Differences in licence conditions CC and European case studies**

<table>
<thead>
<tr>
<th>CC</th>
<th>NL</th>
<th>Norway</th>
<th>NRW</th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-line acceptance of licence is available (no paper application or signature required).</td>
<td>Sometimes</td>
<td>Need formal agreement</td>
<td>Need formal agreement</td>
<td>Need formal agreement</td>
</tr>
<tr>
<td>The user may transfer the information and/or derivatives to a third party without prior consent of the right holder.</td>
<td>No</td>
<td>Only to Norge Digitalt (Digital Norway) participants</td>
<td>Only to public sector parties</td>
<td>No</td>
</tr>
<tr>
<td>All Information is available for (re)use at no upfront charges and free of royalties</td>
<td>Some information</td>
<td>Only thematic (environmental) information</td>
<td>Only for other public sector bodies</td>
<td>Very little information</td>
</tr>
<tr>
<td>No differentiation between types of users</td>
<td>Sometimes</td>
<td>Differentiation between public sector and other users</td>
<td>Differentiation between public sector and other users</td>
<td>Differentiation between public sector and other users</td>
</tr>
<tr>
<td>Licence is valid for the duration of copyright / database right</td>
<td>Sometimes valid for fixed period</td>
<td>Sometimes valid for fixed period</td>
<td>Sometimes valid for fixed period</td>
<td>Only valid for fixed period</td>
</tr>
</tbody>
</table>

The table shows that there are discrepancies in several locations. These discrepancies and shortcomings of Creative Commons are addressed in the following sections.
4.2 Commercial use

One of the cornerstones of CC is sharing information, usually for noncommercial purposes. However, what exactly constitutes ‘commercial use’? In its legal code CC defines noncommercial in article 4b as:

“You may not exercise any of the rights granted to You [the licensee] ... in any manner that is primarily intended for or directed toward commercial advantage or private monetary compensation. The exchange of the Work for other copyrighted works by means of digital file-sharing or otherwise shall not be considered to be intended for or directed toward commercial advantage or private monetary compensation, provided there is no payment of any monetary compensation in connection with the exchange of copyrighted works.”

This definition is clear with regard to a private sector organisation that wants to use the dataset to produce a product or service with the intention to sell this product or service for a profit. But what about use by nonprofit organisations, are they entitled to use data made available under a ‘non-commercial’ condition when they do not intend to make a profit? Should there be a differentiation between public and private schools since private schools are institutes that ultimately intend to make a financial profit? And what about a company representative visiting a client using a car navigation system, does this constitute commercial or internal use? The courts will not only look for a legalese interpretation of the word ‘commercial’ but also look at the contract situation as a whole, when interpreting the situation (Pawlo, 2004). On a national level, some consensus may be reached what the meaning of ‘commercial’ will be, but on an international level this may not be the case. In the Netherlands, the District Court ruled in favour of a CC licensor. A well-known DJ had published photographs of his family on flickr.com under a CC-nc licence. A magazine used some of these photographs without permission. The DJ successfully sued the magazine for breach of the CC licence, although no damages were awarded7.

Therefore, the CC question ‘Allow commercial uses of your work?’ would always have to be answered with ‘yes’, or else the private sector would not be able to use the datasets. Even if they were only to use the datasets for internal use rather than to produce directly value-added services, this may still constitute commercial use, given the uncertainty of the concept ‘noncommercial’ in various jurisdictions. To avoid a potential quagmire, it would be best if only by-nd, by-sa or by licences are used for reusing PSGI.

In most European jurisdictions public sector organisations make PSGI available for producing value-added products and services only after a formal agreement has been negotiated. This allows the public sector organisation to customise licence agreements depending on the type and quantity of data. This is one of the reasons why the current licensing system is not transparent. It might be more practical to replace the current CC noncommercial use symbol with an ‘advance permission’ symbol. The licence condition as it is currently in use by a number of public sector organisations would thus be better represented. It would also avoid a philosophical discussion concerning commercial use. However, it would be better to entirely abolish the distinction between noncommercial (internal use only) and commercial (external use). Especially as a noncommercial CC licence will not prevent the user from reproducing the data using web services or posting the data on websites. As long as there is no financial gain for the licensee, the licensee is allowed to do so as long as the right attribution has been made.

4.3 Derivatives and Share Alike

In the older CC-versions there was a mismatch between different ‘some rights reserved’ licences such as CC and FDL. If you wanted to remix works issued under different ‘some rights reserved’ licences you could not make the derivative product available if the derivative has to be licensed under exactly the same licence as the original. By selecting one ‘some rights reserved’ licence over the other, you were in breach of the original licence and therefore neither could be selected. Version 3.0 of CC, released in the spring of 2007, has

7 Curry v Audax Publishing, District Court Amsterdam, 09-03-2006.
rectified these incompatibility problems. Products may now be made available under other types of open content licences, as long as they have the same properties.

The CC licence concepts of ‘no derivatives’ and ‘share alike’ also may pose a problem if the aim is to make datasets available for value-added products. If PSGI is only to be used without being able to produce derivatives, then it will only be suitable for internal business processes or for end users. Whilst this makes the licence suitable for GI reuse by secondary users and end users, it will not stimulate value adding by tertiary users. The same applies to the share alike option. In a creative environment the concept of sharing works, adapting them and making the derivatives available under similar conditions can be very important. Institutes like Wikipedia could not exist without share alike licences. But when PSGI is made available to tertiary users for value adding, the concept of making the value-added services and products available under the same conditions would be counterproductive. The concepts are therefore only suitable to make PSGI available to secondary users and end users, provided the GI was supplied for no more than marginal costs of dissemination. This constitutes discrimination for different types of users which is in conflict with the nondiscriminatory provision in the PSI Directive.

PSGI licences found typically are nontransferable licences without so-called viral use conditions (licences conditions requiring derived works should be made available under the same some-rights-reserved conditions). Therefore, the share-alike condition of CC cannot be applied in these instances.

4.4 FEES AND ROYALTIES

CC aim to protect some rights of the author, which should also include the right to receive fair compensation. But CC also stated in their earlier licence conditions that the licensee is under no obligation to pay “any royalties, compulsory licence fees, residuals or any other payments”. However, in a number of jurisdictions collective music rights systems are in place. With version 3.0 CC addresses this problem of compulsory contributions to collecting societies. In the older licensing versions the right to collect royalties had to be waived. CC has now acknowledged that this is not possible to do so in those jurisdictions where there are statutory or compulsory licensing schemes. Whilst this amendment addresses the problem of musicians having to compulsory join a collection society and still wanting to publish their work under a CC licence, it does not directly address the problem of a licensor intending to charge licence fees and/or royalties. CC licences as such therefore seem to be effectively only suitable for organisations that intend to make the datasets available free of charge. However, if PSGI is made available for dissemination costs, then one does not pay for the actual dataset. Rather, one pays a compensation for setting up and maintaining a web service, cost of DVD, or postal charges. In that case we hold the opinion that a CC licence can be used for PSGI as long as it is clear that the data itself is free and one only pays for the costs of dissemination. However, much European PSGI is available at a price exceeding the marginal cost of dissemination. In these instances, CC cannot be applied.

4.5 LIABILITY

Geo datasets incur a different liability regime than most other data. Suppose a company is commissioned by a municipality to produce a road system for a new housing development. Afterwards it turns out there is a mistake in the dataset because two street names were switched. The municipality suffers losses because they have used the dataset to produce a new street plan and have already distributed 10,000 copies. Others may suffer losses as well because of this mistake. What if one of the residents suffers a heart attack and dies because the ambulance was delayed due to the street name mix-up? Can his relatives claim damages? (van Loenen et al., 2006).

We will not go into the legal details of liability here as liability regimes differ in Europe. In general though, in the Netherlands, if a public sector organisation makes (geographic) data available for reuse by third parties, the datasets should be accurate and exhaustive enough to carry out the original public task (van Loenen et al., 2006). The metadata should display the original use of the dataset. Potential users of the dataset can determine if the dataset is suitable for the intended (re)use by inspecting the supplied metadata. However, although
INSPIRE will prescribe metadata standards, in practice metadata is poorly maintained, especially for older GI and non-GI PSI. In the CC licenses v3.0, works are offered ‘as-is’ unless mutually agreed by parties in writing. So, if the metadata is incomplete, liability will remain a problem as the licensee does not have enough information to determine the suitability of the data. Furthermore, consumer protection legislation might prevent the use of a total disclaimer. In the Netherlands, for example, disclaiming liability for gross negligence is not allowed in general conditions between companies and consumers (it is on the so-called black list). The Dutch CC license allows for such legal provisions at the end of article 6.

4.6 In summary

This means that – apart from a public domain licence – in effect only one out of the six CC licences can be considered for supplying PSGI, namely the by licence. This conclusion corresponds with the conclusions of research carried out about the suitability of CC-licences for public sector information in general (van Eechoud and van der Wal, 2008). Nevertheless, with the additional symbols as shown in figure 1, most of the current PSGI policies would be covered. However, when changes are to be made to the original CC model, the name ‘Creative Commons’ can no longer be used. The name ‘Geo Shared’ is more applicable to an adapted model. Geo Commons seems more obvious as a moniker, but is not so suitable. The name Commons implies communal use – that is, prior permission for use does not have to be sought before the GI is used. This may be misleading, hence the name Geo Shared.

5 GEO SHARED LICENSES

Although CC licences are considered for PSGI in Queensland (Australia) (QSIC, 2007; QSIO, 2006) and are successfully used in the Netherlands for the New Map of the Netherlands, available at no cost, the analysis of licences currently available for PSGI in Europe shows that a one-to-one translation into CC licences is not possible (see table 3). The first difference – formal licences – can be solved by online registration and password-controlled entry procedures. Many organisations which supply GI already use online registration forms and password-controlled entry procedures. The second difference does not pose a problem either as it can be included in the legal code. To make this condition clearer on the common deed, the noncommercial use symbol could be replaced with another symbol. The third difference could be overcome by including an extra symbol to indicate the difference between free or fee-based data. To indicate the last difference, another symbol could be included on the common deed. However, it is debatable if this is necessary. A lot of GI dates quickly, having most of its value in the degree to which it is up-to-date. By adapting the existing schema for CC with additional symbols, we can no longer use the name Creative Commons. Therefore, we will refer to the new schema as Geo Shared licences. This would be in line with the recommendations of the National Research Council (2004).
= **Attribution.** Others may copy, distribute, display, and perform the copyrighted work — and derivative works based upon it — but only if they give credit the way the rightholder request.

= **Permission in advance.** Data and/or derivative products may only be made available to third parties after obtaining permission from right holder in advance.

= **Costs.** The user is required to pay licence fees and/or royalties for the use of the data/information.

= **Limited period.** The Data and/or derivative products is available for a limited period, see full licence for exact period

**Figure 1: Geo Shared licences**

The licence conditions are reduced to the following terms:

1. Others may use your data as long as they credit you for the original creation the way you request it.
2. Others may use, copy, display and distribute your data — and derivative products based upon it — either for commercial or noncommercial purposes, but only after they have contacted you in advance the way you request it (prior permission).
3. The data are available for an upfront fee and/or attracts royalties payable (fee-based).
4. The data are only available for a limited period, either on a subscription basis or data to be returned after a specified period (time limit).
Table 3: Geo Shared license framework

<table>
<thead>
<tr>
<th>Licence type</th>
<th>Icons</th>
<th>Licence conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribution</td>
<td>![Attribution icon]</td>
<td>This license lets others copy, build upon and distribute the data without prior permission, as long as they credit the rightholder for the original creation.</td>
</tr>
<tr>
<td>Attribution Time</td>
<td>![Attribution Time icon]</td>
<td>This license lets others copy, build upon and distribute the data without prior permission, as long as they credit the rightholder for the original creation. The data are only available for a limited period.</td>
</tr>
<tr>
<td>Fee-based</td>
<td>![Fee-based icon]</td>
<td>This license lets others copy, build upon and distribute the data without prior permission, as long as they credit the rightholder for the original creation. The data incur upfront fees and/or royalties payable.</td>
</tr>
<tr>
<td>Fee-based Time Limit</td>
<td>![Fee-based Time Limit icon]</td>
<td>This license lets others copy, build upon and distribute the data without prior permission, as long as they credit the rightholder for the original creation. The data incur upfront fees and/or royalties payable. The data are only available for a limited period.</td>
</tr>
<tr>
<td>Prior Permission</td>
<td>![Prior Permission icon]</td>
<td>This license lets others copy, build upon and distribute the data only after prior permission. The rightholder must be credited for the original creation.</td>
</tr>
<tr>
<td>Prior Permission Time</td>
<td>![Prior Permission Time icon]</td>
<td>This license lets others copy, build upon and distribute the data only after prior permission. The rightholder must be credited for the original creation. The work is only available for a limited period.</td>
</tr>
<tr>
<td>Priority Fee-based</td>
<td>![Priority Fee-based icon]</td>
<td>This license lets others copy, build upon and distribute the data only after prior permission. The rightholder must be credited for the original creation. The work incurs upfront fees and/or royalties payable.</td>
</tr>
<tr>
<td>Priority Fee-based Time</td>
<td>![Priority Fee-based Time Limit icon]</td>
<td>This license lets others copy, build upon and distribute the data only after prior permission. The rightholder must be credited for the original creation. The work is only available for a limited period. The work incurs upfront fees and/or royalties payable.</td>
</tr>
</tbody>
</table>

6 CONCLUSION

Only if the restrictive reuse conditions and financial issues have been resolved is value-added use expected to thrive. Until that very moment, the introduction of a CC inspired concept such as the Geo Shared concept in the world of GI may help to increase the transparency and consistency of license agreements, especially when combining data from different sources. Although CC licences are not suitable for all types of GI licences, they do provide a tool to review the current PSGI licences. Both CC and Geo Shared licence categories provide a way to review and categorise current licences. The Geo Shared licensing concept also enables the harmonisation of fee-based datasets. Using symbols in a layman’s version of licence agreements makes it easier for users to identify datasets suited to specific purposes. Uniform and legible licence agreements would certainly help to make the whole process more transparent, especially when combining datasets from different suppliers. In this way, the Geo Shared concept is a valuable contribution to the development of many geographic information infrastructures around the world, including INSPIRE. Therefore Geo Shared licences should also be considered as a serious option within INSPIRE as one concept of
transparent harmonised licenses for geographic information as a key for the utilisation of
the geographic information infrastructure in Europe. To the same end, other nations across
the globe may take advantage of the Geo Shared concept by harmonising existing licence
conditions of PSGI. Ultimately, this may result in a standard set of licences for PSGI
providing the consistency and transparency required by value-added resellers.

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Network – Liberty United’ (Geoloketten – Vrijheid in Verbondenheid) in the framework of the Bsik
program ‘Space for Geo-information’.

ABBREVIATIONS
CC Creative Commons
CLA Collective Licence Agreement
FDL Free Documentation Licence
GI(I) Geographic Information (Infrastructure)
HMLR Her Majesty Land Registry
INSPIRE Infrastructure for Spatial Information in Europe
IPR Intellectual Property Rights
MSA Mapping Services Agreement
ND Norge Digitalt (Norwegian Geographic Information Infrastructure)
NE Norsk Eiendominformasjon (Norwegian GI One-Stop Shop)
NRC National Research Council
NRW North Rhine Westphalia (German State)
OS Ordnance Survey (United Kingdom)
PS(G)I Public Sector (Geographic) Information
SDI Spatial Data Infrastructure
SK Statents Kartverk (Norwegian Mapping and Cadastre Authority)
UKHO United Kingdom Hydrographic Office
VAR Value Added Reseller
Wob Wet openbaarheid van bestuur (Dutch Freedom of Information Act)

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Future SDI – Impulses from Geoinformatics Research and IT Trends

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Abstract

The term Spatial Data Infrastructure (SDI) was defined in the nineties as a set of policies, technologies and institutional arrangements for improving the availability and accessibility of spatial data and information. SDIs are typically driven by governmental organizations, and thus follow top-down structures based on regulations and agreements. The drawback is that it renders SDIs less easily

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capable of evolving with new technological trends. While organizations are still struggling to implement SDIs, the World Wide Web is increasingly developing into a Geospatial Web, i.e. one that extensively supports the spatial and temporal aspects of information. This article is our contribution to the discussion on the future technological directions in the field of SDIs. We give a conceptual view of the dynamics of both SDIs and the Geospatial Web. We present a picture of the SDI of the future, one which benefits from these developments, based on an analysis of geoinformatics research topics and current ICT trends. We provide recommendations on how to improve the adaptability and usability of SDIs as to facilitate the assimilation of new ICT developments and to leverage self-reinforcing growth.

**Keywords:** SDI, Information Infrastructures, Geoinformatics, Geospatial Web, Linked Data

1. **INTRODUCTION**

Increasing awareness of the global challenges that mankind faces today comes with the realisation that only by implementing significant changes in the way we organize our lives on planet Earth will we be able to cope with these challenges. This necessitates both a better understanding of our biophysical and social environment and better management of our activities on all levels and at all scales, whether a global business entity, a national public authority, or a private individual.

Improving our understanding requires a joint effort across several disciplines, organisations and Information Infrastructures (IIs), which support communication and collaboration efficiently (Goodchild, 2008; Craglia et al., 2008). This includes providing a means of sharing spatio-temporal data and computing capabilities, so as to create multi-participative decision-supporting environments, which enable multidisciplinary research teams and decision makers at all levels to achieve their objectives (Hey and Trefethen, 2005).

Spatial data infrastructures (SDIs) are currently the best approximation to these spatial community concerns. SDIs are described as a set of policies, technologies and institutional arrangements leveraging the provision and use of standardized spatial data and processing services, to assist diverse expert user communities in collecting, sharing and exploiting geospatial information resources (Phillips et al, 1999; Nebert, 2004; Masser, 2005; Masser et al, 2007; Bishop et al, 2000; Davis et al, 2009; Vandenbroucke et al, 2009).

The development of SDIs is, in particular, driven by public authorities, like
national mapping or environmental agencies (Béjar et al, 2009), whose business processes often involve spatial data and whose tasks are often related to specific territories and geographical locations. Hence any means of exchanging of spatial information between these public authorities and private individuals, business entities or other public bodies saves considerable time and costs. Most importantly, a better information base improves the quality of plans and decisions, though it is challenging to express this in monetary terms.

A prerequisite for implementing an SDI in the public sector is a legal framework that lays down the goals and principles, including details relating to content and technologies as well as the rights and obligations of the parties involved. The most prominent European example is INSPIRE, the Infrastructure for Spatial Information in the European Community (INSPIRE, 2007) which is a European-scale SDI, based on member states’ national SDIs. The INSPIRE Directive has been transposed into the member states' national legislation. The European member states are obliged to provide certain data, metadata and web services, so as to support policies and activities that have an impact on the environment. The INSPIRE Guidance Documents recommend very detailed specifications, which have to be implemented so as to achieve interoperability between all the SDIs and their components.

Today, more than ten years after the first working groups and action plans on INSPIRE were first established, INSPIRE displays a significant footprint, even if it is not yet fully operational. The framework directive has been implemented in national laws, organizational structures and workflows have been adapted, and off-the-shelf software now supports the required interfaces and processes. The paradigm of a standards-based open service-oriented architecture has gained broad acceptance. In parallel, and corresponding with the implementation of INSPIRE, national and regional SDIs have been developed, with many spatial content offerings and applications now up and running.

Nevertheless, SDIs have so far failed to achieve the desired level of impact and penetration in the geospatial community. The problem is that SDIs generally suffer from a low rate of user participation and a scarcity of resources (Ackland, 2009; Díaz et al, 2011), a lack of maintenance as they grow in complexity (Béjar et al, 2009), and difficulties in efficiently discovering and processing data (Scholten et al, 2008; Craglia et al, 2007; Craglia et al, 2008; Granell et al, 2010). These shortcomings are obvious, for example in the emergency management domain, where easy access to up-to-date information is crucial for minimizing damage and saving human lives (Diehl et al, 2006; Zlatanova and Fabbri, 2009).

This contrasts with the fact that mainstream IT is developing at a fast pace, offering new and improved means of sharing resources and organizing multi-participative environments across disciplines and user profiles. The Web is evolving into a Geospatial Web, i.e., independently of any SDI initiatives, the Web is increasingly and extensively supporting the spatial and temporal aspect of
information. Ubiquitous access, location-aware devices, and user-centric applications are creating a new user experience, which boosts consumers’ expectations of the Web’s spatial capabilities. The crowd of individual users is increasingly participating in the processes of collecting, communicating and using geographical information. Volunteered Geographic Information (VGI) (Goodchild, 2007) has gained relevance as a source of information which complements the authoritative spatial data.

We have introduced the full picture describing the characteristics associated with the way SDIs are managed and used: building methodologies, data policies and deployment laws are indeed crucial parts on the SDI future development. However the scope of this work focuses on analyzing the technological components of SDIs. From the technological point of view, we are currently observing a widening gap between classic SDIs and what we call the Geospatial Web. Both are improving, but at different speeds, but what is the future of SDIs? What momentum is being created from research activities in the field of geoinformatics? What will be the impact of current IT trends which are already shaping the Geospatial Web?

This article addresses some of these questions. We begin by analyzing the inherent dynamics of SDIs, as an aid to understanding the diverging development of SDIs compared to that of the Geospatial Web. Section 3 analyzes selected fields of research and IT trends, and assesses their relevance in future SDI developments. Section 4 gives a structured overview of IT trends and their anticipated impact on SDIs. Section 5 aggregates the findings of this analysis as a set of hypotheses on the future development of SDIs.

2. DYNAMICS OF (SPATIAL) INFORMATION INFRASTRUCTURES

According to the theories of Hanseth and Lyytenen (2010), the term information infrastructure (II) denotes “shared, open, heterogeneous and evolving socio-technical systems consisting of a set of IT capabilities and their users, operations and design communities” (Hanseth and Lyytenen, 2010). Compared to information systems, IIIs (like the Web) are more complex, recursively composed of IT capabilities and controlled by a distributed set of stakeholders across multiple domains. With due consideration for this complexity, Hanseth and Lyytenen (2010) propose a specific set of design principles and rules for the development of IIIs, which is more about cultivating a self-organising system than a straightforward engineering process. Referring to the theory of Complex Adaptive Systems (CAS) Hanseth and Lyytenen (2010) emphasise bootstrapping and adaptability as the main challenges facing II development. The bootstrapping problem addresses the fact that an II is useful and self-energising only if it has a significant and growing installed base, in terms of actively used II components and users. The adaptability problem reflects the fact that a lack of flexibility
regarding the adaptation of new and improved technologies can constrain the use and further development of IIs.

It seems evident that both bootstrapping and adaptability are in fact significant issues for SDIs. As for the former, after more than a decade, the SDIs installed base still consists predominantly of pre-operational service offerings, and regarding the latter, even though the structure of legal frameworks considers the life cycle of technologies, it will take years to manage any substantial changes, due to the complexity and the characteristics of the processes involved.

In fact, the development of SDIs is not in line with several of the rules and principles of design proposed by Hanseth and Lyytenen (2010). These are:

2.1. **Generate Attractors that Bootstrap the Installed Base**

The goal as presented by Hanseth and Lyytenen (2010) is to attract a critical mass of users, so as to gain both acceptance and a momentum for self-reinforcing growth. This would be achieved by designing and implementing the infrastructure in such a way that it directly provides and encourages substantial use. Furthermore, it should be built upon an existing installed base and be easy to implement so as to support its acceptance. The installed base should be subsequently extended by persuasive tactics in order to gain further momentum.

However, it is the case that the majority of SDI implementations begin with extensive prototyping and pilot phases, which are not suitable for operational use. Most developments are driven by data providers and their offerings are not aligned to users’ requirements.

Most SDIs are built upon an existing installed base. However, specific data models and interfaces are required, which need to be implemented by both users and the Geo-IT industry. This requires investment, which impedes acceptance and slows down adoption.

2.2. **Make the System Maximally Adaptive and Variety-Generating to Avoid Technology Traps**

The goal as presented by Hanseth and Lyytenen (2010) is to allow for new and improved technologies to replace parts of the II’s technology stack. Providing alternatives would support users in selecting the best of breed, which would then establish the next de facto standard for implementing an II with improved capabilities. This would necessitate a modularized structure with low dependencies between the individual components.

However, SDIs are predominantly governed by public authorities, essentially relying on a combined bottom-up & top-down process: ideas, requirements and concepts fuel a political and legislative process, which results in a set of visions, strategies, decisions and regulations, which have to be implemented top down at
least throughout the hierarchy of the public administration. There is no alternative
to this process for public authorities when it comes to actively managing change
on a national and transnational scale. On the other hand, it makes SDIs rigid and
less able to evolve with new trends and technologies.

In fact, what we are observing is the agile development of the World Wide Web,
which is not really a governed infrastructure and always seems to be evolving at
the edge of chaos (Hanseth and Lyytenen, 2010). Actually, the Web’s
independence of policies and institutional arrangements provides degrees of
freedom that allow for ultrafast adoption of new ideas and developments.

One of the main conclusions we can state is that SDIs are intrinsically less
adaptive than, for instance, more general information systems such as the World
Wide Web, a situation which has led to a growing gap between the capabilities
of SDIs and those of the overall information infrastructure.

3. (MOVING FORWARD) AN ANALYSIS OF GEOSPATIAL RESEARCH AND
IT TRENDS

The term innovation denotes something new that has gained certain relevance in
practice (Roth, 2009). While it is easy to describe current innovations in the field
of information infrastructures, for example, by referring to the growth rate of an
existing installed base, it is quite difficult and afflicted with uncertainty to predict
these developments, due to the complexity and non-linear behaviour inherent in
IIs. But it is obvious that trends in the overall IT infrastructure which are beneficial
to SDIs create a certain momentum for innovation in SDIs.

The following section discusses research and IT trends and their relevance to
SDIs. Some of these trends, such as linked open data, are still research topics
and in an early phase of their life cycle. Nevertheless, we regard them as trends if
their growing installed base and user community indicate their increasing
relevance in the market.

The topics and their analysis are based on each authors’ individual expertise,
background and research, an overview of SDI research agendas (Gore, 1998;
Phillips et al, 1999; Bernard et al, 2005; Craglia et al, 2008; Goodchild, 2010),
and IT trend reports (Bundesministerium für Wirtschaft und Technologie, 2010;
Capgemini, 2011; Dutta and Mia, 2011; European Commission, 2010; GGIM,
2012) and an internet survey of qualified IT trend statements (CIO/Forrester IT
Trends 2011-2013\textsuperscript{1}; BitKom Questionaire 2010\textsuperscript{2}; Gartner IT-Trends 2011\textsuperscript{3}; U.S. Federal IT Market Forecast 2011-2015\textsuperscript{4}).

3.1. Architectural Styles and Interoperable Interfaces

In order to address common user requirements, such as search and retrieval of content, major research carried out in the SDI field has focused on defining standards to improve systems interoperability. Desser et al (2011) describe standardization as being the relevant factor for increasing interoperability to deploy business processes on top of SDIs. Interoperability has been mentioned over the years in both SDI and Digital Earth research agendas, emphasizing different levels. Two relevant pieces of work (Sheth, 1999) and (Goodchild et al, 1999) differentiate mainly between system, syntax, structure or schema and semantic interoperability levels.

While the Internet serves as the basis for systems interoperability, middleware components support distributed computing by means of Web Services and XML-based standard interfaces. Syntactic interoperability includes the ability to deal with formatting and data exchange, adopting ad hoc standards (Sheth, 1999; Feng, 2003) to achieve it. Schematic interoperability is described by common classifications and hierarchical structures while semantic interoperability harmonizes meanings of terms. They can be improved by using metadata standards, data schemas and ontologies (Bishr, 1998). There is a wide range of interoperability standards available for the integration of information systems (Mykkänen and Tuomainen, 2008). In SDIs, interoperability is ensured most prominently by efforts by ISO/TC211 and the Open Geospatial Consortium (OGC) promoting syntactic interoperability through the use of web services (Percivall, 2008). The existing specifications have been shown to help when setting up operational SDI for sharing distributed geospatial data (Bernard et al, 2005).

SDIs exemplify the adoption of a service-oriented architecture (SOA) style to enable distributed access to heterogeneous spatial data and services through a set of common specifications and standards (Yang et al, 2010). Despite the fact that multiple operational SDIs are running worldwide, SDI interconnection and scalability is still an issue, due mainly to the lack of connectivity between SDI nodes (Schade et al, 2010).

Nowadays, this lack of connectivity and the complexity of the SOA-oriented SDIs have given rise to a search for alternative architectural styles, such as representational state transfer (REST) (Granell et al, 2012), which is aligned with the same principles that shape the Web. Some authors (Foerster et al, 2011a, 2011b).

\begin{itemize}
\item \textsuperscript{1} http://www.cio.de/strategien/methoden/2252382/
\item \textsuperscript{2} http://www.cio.de/strategien/2220403/
\item \textsuperscript{3} http://www.gartner.com/it/page.jsp?id=1454221
\item \textsuperscript{4} http://www.marketresearchmedia.com/2009/05/23/us-federal-it-spending-forecast-2010-2015/
\end{itemize}
Mazzetti et al., 2009; Granell et al., 2012) describe how the adoption of REST principles, particularly the use of HTTP as an application protocol, may be beneficial in scenarios where ad hoc composition of geospatial services is required, something which is common among most non-expert users of SDI. In general, the realization of distributed SDI components following the REST principle enables a more generic and lightweight way of providing geographic information and are more specific and oriented towards geospatial functionality than OGC-based services (Schade et al., 2012).

3.2. Cloud Computing

Even in the first GSDI agenda in the nineties, efficiency in accessing data was identified as a main challenge; the issue of who is in charge of hosting data and tools so as to provide good performance has been a matter of discussion ever since. Efficiency may be examined from two different points of view. Firstly, the hosting of data and service execution has to be realized efficiently from an economic perspective. Service providers should avoid investing in rarely used hardware (by migrating to cloud computing platforms) and share computational resources and knowledge beyond organizational boundaries (increasing interoperability).

Cloud computing is one of the latest trends in the mainstream IT world (Driver, 2008; Buyya et al., 2009). The cloud metaphor describes an approach in which applications, services and datasets are no longer located on individuals' computers, but distributed over remote facilities operated by third party providers (Foster et al., 2008).

Cloud computing has already influenced recent research agendas such as (Craglia et al., 2008) and the Beijing declaration in 2009, which addressed the adoption of cloud computing in realising highly available and highly scalable spatial applications in order to increase an SDI's quality of service (QoS) (Baranski et al., 2011). These can range from classic web service qualities (e.g. service performance, response time and availability) to geospatial data quality (e.g. the degree of uncertainty in measured and processed data).

In cloud environments, users can allocate computational resources without requiring human interaction with a resource provider (on-demand self-service) (Mell and Grance, 2009). Examples of such resources include storage, processing, memory, network bandwidth, and virtual machines. These resources and their capabilities are available over the network via standard mechanisms and simple web-service interfaces (broad network access). The providers of resources (physical and virtual resources) have to cope with multiple users and their dynamically changing demands (resource pooling). From the user's perspective, the availability of resources in the Cloud often appears to be unlimited. They can be acquired from the resource provider in any quantity at any
time, in order to scale applications, services and storage depending on use-case-specific requirements (rapid elasticity).

Resource usage in cloud environments can be monitored and reported, providing transparency for both the users and the resource providers (measured service). All these cloud characteristics are used to enable users to run their web or desktop-based applications in the cloud, without managing the hardware infrastructure (software as a service, SaaS). Resource providers can offer runtime environments in the cloud, in which users can deploy their applications created using programming languages and tools supported by the provider (Platform as a Service, PaaS). Furthermore, resource providers can offer complete access to virtual machines, in which users have control over operating systems, storage, deployed applications, etc. (Infrastructure as a Service, IaaS). However, when a resource provider makes his resources available in a pay-as-you-go manner to the general public, it is called a public cloud (Armbrust et al., 2010). When cloud technologies are used to manage an internal data centre and when such a data centre is not made available to the general public, it is called a private cloud. In a so-called hybrid cloud, a private cloud is combined with resources of a public cloud in order to handle tasks that cannot be performed in the local data centre, due to general hardware limitations and a temporarily heavy workload.

3.3. Distributed Processing and Uncertainty

While interoperability between data sources has been achieved to a degree in SDIs, the integration of geoprocessing functionality into such infrastructures, in order to provide an essential means of generating information out of basic data, is still an open challenge. Research on service granularity and the adoption of new standards-based interfaces for geoprocessing, such as the OGC Web Processing Service (WPS) (Schut, 2007), aim at facilitating the integration of distributed geoprocessing functionality in SDI applications (Granell et al., 2010; Foerster et al., 2011b). Furthermore, data provenance and tractability is a crucial issue for the distributed processing to offer information about its utility, accuracy and fitness for a particular user or use case.

Main research topics related to distributed geoprocessing, as originally outlined by Brauner et al (2009), are:

1. Service orchestration strategies for improving performance and semantic descriptions. Service orchestration deals with the question of how to combine several singular geoprocessing steps into a more complex workflow. This includes developing mechanisms to describe complex geospatial workflows in terms of, for instance, Business Process Execution Language (BPEL), but also developing mechanisms and user interfaces to discover geospatial processing functionality in the web and to integrate this functionality in geospatial workflows in an ad-hoc manner.
2. Finding the appropriate granularity with which to map workflow steps to geoprocesses (Granell et al., 2010). This also relates to the issue of performance in the geoprocessing web. Reducing a complex workflow to several small processes may increase the performance of each individual step and allow the parallelization of several steps, but it will also increase the communication overhead when transferring the inputs and outputs between the different processing steps.

3. Complex processes dealing with large data volumes. New technologies such as the distribution of processing over GRIDs or deploying it in clouds will improve performance.

4. The problem of adding semantics to geospatial workflows to allow the discovery and automation of geospatial workflows. Research projects like the ENVISION project (http://www.envision-project.eu/) aim to define common methods on how to integrate semantics. Recently, Janowicz et al. (2010) proposed a mechanism for semantically enabling SDIs by using common service interfaces such as the OpenGIS catalogue service and the WPS for adding semantics. This information will handle issues such as data provenance, model uncertainty and processing fitness for a particular use.

Along with this trend of deploying distributed geoprocessing on top of an SDI, there are a number of new issues and trends to be addressed. Since users process data in a distributed form, and do not own the algorithm itself, distributed processing needs to include mechanisms for evaluating processing results. The user requires information regarding process quality to allow him to deduce the accuracy of the result. Therefore, it is not just technical integration, but the knowledge bases themselves need to be developed. This requires, for instance, defining vocabularies for simple geoprocessing functionality, such as simple topological operators, and defining common process ontologies as well as specialized ontologies for complex workflows. Finally, any geospatial information is only able to represent the universes of discourse to a degree. The difference between a discourse in some domain and the process descriptions and data representing it cannot be quantified exactly, but only propagated to a certain extent, by indicating the level of uncertainty in the data (provenance and after processed). One common way to quantify this uncertainty is by using probability distributions such as those proposed by Heuvelink (1998). Usually, neither the uncertainty in the data nor the uncertainty in the information generated from basic data is integrated in SDIs or the geoprocessing web.

The INTAMAP project recently provided an example of how to communicate uncertainty resulting from the interpolation of point measurements (Pebsma et al., 2010). The UncertWeb project (http://www.uncertweb.org) is currently investigating how to add uncertainty propagation to complex web-based geospatial workflows, such as air-quality prediction models (Bastin et al., 2012). Questions of how uncertainty can be represented and easily added to spatial
(and/or temporal) workflows deployed in the Web and how uncertainty can be propagated in web-based geospatial workflows without knowing the internals of the processing steps need to be addressed.

3.4. Participative Platforms and User-Generated content

Content provision has been traditionally associated with public administrations. Along with the evolution of SDIs and their growth in size and complexity, authors increasingly stress the need for content provision facilitators. Two factors are considered as the main challenges: firstly, SDI top-down building methodologies do not encourage or allow all stakeholders to participate and secondly, publication mechanisms are complex, provoking a lack of active user participation, and in turn, a scarcity of content (Díaz et al, 2011). On the other hand, the versatility of Web 2.0 systems, being populated with user-generated content, contrast to SDI maintenance and publication mechanisms since these Web 2.0 systems provide mechanisms that could be adopted to lower the barrier in SDI publication mechanisms (Díaz and Schade, 2011).

Providing up-to-date and full coverage of data is a requirement of any information system. Users with sensor-enabled devices can collect data and report phenomena more easily and cheaply than through other official sources. Crowd-sourced information is based on the assumption that non-expert users are able to contribute data in a specific form and for a specific purpose. This data is organized and structured in communities, which contribute to a specific task.

This emerging trend is heavily supported through improved user interfaces and ubiquitous web-access. Example applications are Mechanical Turk and Wikipedia and. Furthermore, encouraged by sensor-enabled devices, user generated content contains the information about content location, and we witness the appearance of citizen-based geographic applications such as Open Street Map\(^5\).

The evolution of the role of the user from a pure consumer towards a provider profile has resulted in concepts such as Web 2.0, neogeography (Turner, 2006), cybercartography (Tulloch, 2007) or volunteered geographic information (VGI) (Goodchild, 2007). This trend is mainly characterized by active user participation. Ordinary citizens provide and share information (for the most part with a spatial temporal reference), for instance in the context of municipal activities (Carrera et al, 2007) or environmental monitoring (Davis et al, 2009), this new source of spatial information is increasingly being adopted by wide audiences and media (Sui and Goodchild, 2011).

Current research trends emphasize citizen-active participation to enrich official information (Craglia, 2007; Goodchild, 2010). This can be addressed in two ways, firstly by integrating available user-generated resources in the SDI context, and

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\(^5\) http://www.openstreetmap.org/
secondly by reconceptualising the role of SDI users (Budhathoki et al, 2008), allowing SDI users to be not only consumers but assisting users to participate directly in providing content to SDI. This content, mostly geo-referenced, thanks to the smart devices currently available, allow user to provide geographic information enriched by the user context. Since we consider different user profiles to be participating more actively in data provision, SDI agendas stress the need for both mechanisms for describing and identifying users and data provenance and mechanisms for assessing data quality and consistency.

3.5. Access Dynamics: Sensor Web and the Web of Things

One of the main goals of spatial information infrastructures is to provide vast amounts of dynamic data on the current state of the Earth, at high spatiotemporal resolution, for continuous monitoring and geosensing of the world, as an aid to efficient decision making (Craglia et al, 2008). There is a need to improve data dynamics by developing technology to capture real-time and high-spatial-resolution data (Gore, 1998). Such dynamic data is provided by various geosensors, ranging from weather or water gage stations, over complex marine sensors, to unmanned aerial vehicles or satellites. To integrate such geosensors and their data with Spatial Information Infrastructures, the Sensor Web Enablement (SWE) technology can be used. SWE is a framework of web service and data encoding specifications defined by OGC and enables the interoperable discovery and tasking of sensors, as well as the access to measured sensor data and realizes eventing and alerting (Bröring et al, 2011). SWE has already found its way into practise and application, e.g., the European Environment Agency (EEA) utilizes SWE to offer air quality observations in an interoperable manner (Jirka et al, 2012).

New kinds of mobile devices not only provide users with tools to access more dynamic information, but also with sensor-enabled capabilities for capturing and providing high-resolution data. Recent trends indicate that by 2014 the mobile-user community will become bigger than that of desktop users in the Internet. This will impact heavily on how web-based applications are used and put into context. Influential factors will be the limitations of display size, battery consumption and the capture of massive amounts of data by sensors in the mobile device in a constantly changing environment. The environmental context is at present mainly determined by location (measured by GPS), noise (measured by microphone), light, and velocity/attitude (measured by gyroscope). Another trend, visible in today’s Web landscape, is the emergence of physical objects in the virtual space. Examples of such objects connected to the Web are intelligent household appliances, embedded and mobile devices, and networks of stationary or mobile sensors.

6 http://www.morganstanley.com/
This connection of real-world objects with the Internet reflects the vision of the Internet of Things (Gershenfeld et al, 2004). Possible applications in the Internet of Things are influenced by the idea of ubiquitous computing (Weiser, 1991). They range from smart shoes posting running performance online, the localization of goods in the production chain, to the calculation of car-insurance costs based on kilometres actually driven. Research topics benefiting the technical realisation of the Internet of Things, include protocol stacks for the Internet Protocol (IP) standard, optimized for smart objects (e.g., IPv6, 6LoWPAN) (Hui and Culler, 2008), naming services for objects (EPCglobal, 2008), or the unique identification of objects (e.g. RFID).

The Web of Things (Guinard and Trifa, 2009) can be seen as an evolution of the Internet of Things. It leverages existing Web protocols as a common language for real objects to interact with each other. HTTP is used as an application protocol rather than a transport protocol as is generally the case in web service infrastructures, such as OGC’s Sensor Web Enablement framework. Resources are identified by URLs, and their functionality is accessed through well-defined HTTP operations (GET, POST, PUT, etc.). Hence, Web of Things applications follow the REST paradigm (Fielding and Taylor, 2002). Specific frameworks (Pinto et al, 2010; Ostermaier et al, 2010; Bröring et al, 2012) based on REST APIs enable access to things and their properties as resources. These REST APIs can not only be used to interact with a thing via the Web, but website representations of things may also be provided to display dynamically generated visualizations of data gathered by the thing. Then, the mash-up paradigm and tools from the Web 2.0 realm can be applied to easily build new applications. An example application may use Twitter to give notification of the status of a washing machine or enable a refrigerator to post to an atom feed to state which groceries are about to run out. For such use cases, metadata descriptions of things are needed which are based on lightweight languages (e.g. Malewski et al, 2012) to also allow the exchange of those descriptions between Web-enabled things.

The user interaction generally utilizes a cell phone acting as the mediator within the triangle of human, thing, and the Web, as for example shown by Foerster et al (2011c). This emergence of physical things in the virtual world is one of the key technological changes that will shape the Web (Ackerman and Guizzo, 2011).

3.6. Open, Distributed and Linked Data

Among other authors in the nineties, the (GSDI, 1996) and Phillips et al (1999) pointed out the need to move from silos of information to open and distributed infrastructures, to enable information to be integrated from different sources. Related to this, Al Gore suggested the vision of a digital earth (DE) in 1998 and stated: ‘Clearly, the Digital Earth will not happen overnight. In the first stage, we should focus on integrating the data from multiple sources that we already have (Gore, 1998). More recently, Craglia et al (2008), re-evaluating the DE vision,
concluded that 'despite substantial progress, our ability to integrate geographic information from multiple sources is still quite limited'. One of the main challenges toward integrating information is to be able to search and retrieve information. One identified problem relates to the need for manual generation of resource description and cataloguing that keeps provoking the lack of metadata and the difficulties in information discovery in SDIs (Craglia et al, 2008; Díaz et al, 2007). Partial solutions have been achieved by using catalogue services that register metadata and are the key to facilitating the discovery of content available in SDIs (Nogueras-Iso et al, 2005; Díaz et al, 2007).

Today's World Wide Web consists of myriads of documents spanning a gigantic information space. The links between these documents make them traversable with Web browsers. Search engines can analyze links to make contents discoverable and to infer relevance to search queries (Brin and Page, 1998). The research community is currently investigating the migration from the Web of documents to the Web of linked open data. This is a big move, as it not only allows data to be accessed that was not accessible before, but also to have different pieces of data linked to each other.

The Web of Data, if successfully created, will lead to an enormous data space, encompassing data relating to people, companies, publications, books, movies, music, television programmes, genes, proteins, drugs and clinical trials, online communities, and statistical and scientific data (Bizer et al, 2009) There is an increasing amount of linked spatio-temporal data on the Web. One aspect of this movement is to bring sensor data into the linked data cloud (Le-Phouc and Hauswirth, 2009). Note here that sensor observations are traditionally low level - i.e. raw data - and thus it is important to develop mechanisms of obtaining a higher-level, conceptual understanding of different phenomena (Devaraju and Kauppinen, 2011).

Some examples of how linked data are used in the context of SDIs:

1. Efficient and timely crisis management can help to reduce suffering in the aftermaths of crises such as earthquakes, tsunamis, floods or storms. To analyze the complexity of systems such as humanitarian logistics in crisis management, there is a need for integrated human data observations (Ortman et al, 2011). Linked data technologies are capable of interconnecting different observations, and the results can be visualized online.\(^7\)

2. For analyzing processes and operations of complex systems such as environmental and societal systems, there is a need to have 1) well-interconnected data about a system and 2) techniques of statistical computing and other types of reasoning, to find new information, and 3) a

\(^7\) http://linkedscience.org/data/linked-haiti/
means of exploring and visualizing this information. Deforestation and its related phenomena, such as the market prices of agricultural products, together form a complex system. Linked data supports the interconnection of different pieces of data.

3. Identification and categorization of extreme weather events. Weather sensor data is transformed to linked data for efficient linkage. Data reasoning is used to create a higher-level conceptualization of the weather events, for example the categorization of an event as a high wind, winter storm, or a blizzard (Devaraju and Kauppinen, 2011).

4. IMPACT OF IT TRENDS ON THE DEVELOPMENT OF SDIS

This section assesses the potential of the aforementioned trends in geoinformatics research and mainstream IT for the future development of SDIs. To do so, we first recall the main requirements to be addressed by SDIs, before going on to analyze the benefits to be expected from the trends described in Section 3 with respect to these requirements.

4.1. SDI Requirements

The main purpose of SDIs is to support specific specialist communities and fulfill their initial requirements. These requirements can be classified into two types. The first type addresses the user’s expectations of the SDI’s functional capabilities. The second is about the user’s expectations of non-functional aspects relating mainly to the SDI’s usability, such as performance, security and reliability, i.e., the Quality of Service (QoS).

Generally speaking, SDIs are widely known as facilitators in coordinating the exchange of geospatial information (Rajabifard, 2007) (Dessers et al., 2012). In this context, common use cases found in geospatial applications, such as geoportals, show that the main requirements of SDI users are visualization, ease of use, interoperability and mashups, and modelling and simulations (Gore 1998; Goodchild, 2008). Similar user requirements are described in the SDI cookbook (Nebert, 2004): search, visualization, features selections, download and analysis, and processing. In the same way, the GEOSS technological use cases (GEOSS, 2008) define the requirements: search, visualization and exploitation of resources. Furthermore, SDIs need regular maintenance and refinement due to their dynamic nature, the inherent complexity of standardized SDI, and the complex mechanisms of deployment, particularly as SDIs grow (Béjar, et al., 2009).

Figure 1 summarizes the common functional user requirements associated with the relevant steps in the resource life cycle (Díaz et al, 2011). Moving clockwise,

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8 See http://linkedscience.org/data/linked-brazilian-amazon-rainforest/

9 See http://observedchange.com/ontologies/sego/
resources must first be published in the SDI, so that they are available for the other stakeholders. Then, these resources need to be searchable and discoverable in the distributed system. Key elements for increasing the visibility of the resource in the SDI, are metadata and catalogue services (Craglia et al, 2007; Nogueras-Iso et al, 2005). The third step is the ability of these resources to be accessed and visualized. In the last step, users process and exploit these resources, generating new information that should be then ready for publication in the SDI, closing the cycle.

**Figure 1: SDI Resource Life Cycle**

The non-functional requirements mainly address the quality and usability aspects of SDIs, which enable users to perform their workflows in a reliable, secure and effective manner. Secured access is required when exposing sensitive data, as is a certain QoS, which has to be agreed upon and guaranteed by the service providers. Another aspect from a service and content provider’s point of view is that the cost of implementing and maintaining SDI components has to be as low as possible.

Moreover, in specific application domains, such as disaster management, decision-makers have to be provided ad hoc with accurate and up-to-date information. Particularly in the first phases of an event, it is very important to provide fast access to reliable data, to understand the context of the emergency situation (Brunner et al, 2009; Mansourian et al, 2005; Rocha et al, 2005; Scholten et al, 2008, Zlatanova et al, 2006), and to efficiently disseminate the knowledge to the people involved (Almer et al, 2008; Scholten et al, 2008; Nayak and Zlatanova, 2008).
4.2. Potential Impact from Geoinformatics Research and IT Trends

Since SDIs are implemented as an integral part of the overall web based information infrastructure, most of the trends investigated in our analysis will directly or indirectly affect the future development of SDIs. Table 1 summarizes the benefits and the expected impacts on SDIs.

Table 2: Impacts on Required SDI Capabilities

<table>
<thead>
<tr>
<th>Trends in Research and Mainstream IT</th>
<th>Benefits to SDIs</th>
<th>Expected Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural styles and interoperable interfaces</td>
<td>Reduced efforts and costs in integrating and maintaining SDI components</td>
<td>Increasing number of SDI applications, which can be chained and included in more general business models</td>
</tr>
<tr>
<td>Cloud computing</td>
<td>Simplified deployment and maintenance of SDI services</td>
<td>Increasing number of content offerings</td>
</tr>
<tr>
<td></td>
<td>Reduced costs of providing content and applications with a high quality of service</td>
<td>Increasing quality of service</td>
</tr>
<tr>
<td>Distributed Processing and uncertainty</td>
<td>Increasingly easy sharing and reusing of processing capacities</td>
<td>Increases the number of processing tools and applications</td>
</tr>
<tr>
<td></td>
<td>Improved reproducibility and interpretation of computations</td>
<td>Increases the quality of SDI content and its use</td>
</tr>
<tr>
<td>Participative platforms and volunteer geographic information</td>
<td>Low cost contribution of local knowledge and expertise</td>
<td>Increasing amount of data at high space-time resolution</td>
</tr>
<tr>
<td></td>
<td>Private individuals form an SDI stakeholders group, which participates actively in the development of SDIs</td>
<td>Intensified development and use of SDI capabilities</td>
</tr>
<tr>
<td>Access dynamics: Sensor Web and the Web of Things</td>
<td>Improved means for collecting and accessing near real-time information</td>
<td>Increased demand and availability of near real-time data with high spatiotemporal resolution</td>
</tr>
<tr>
<td>Open, distributed and linked data</td>
<td>Simplified integration of heterogeneous data through increasingly shared vocabularies.</td>
<td>Increased availability of information resources</td>
</tr>
<tr>
<td></td>
<td>Improved means for encoding, describing and interlinking data</td>
<td>Improved access to data through links and crawling mechanisms</td>
</tr>
<tr>
<td></td>
<td>Homogeneous model for data and metadata</td>
<td>Improved descriptions of data resources and their quality</td>
</tr>
</tbody>
</table>
The current trend towards more lightweight protocols and data encodings eases the use and integration of technical SDI components. For instance, RESTful interfac ed services require less specialized knowledge for accessing SDI content offerings and for chaining SDI components to deploy scalable applications (Foerster et al, 2011; Janowicz et al, 2011; Granell et al, 2012; Schade et al, 2012). This will help in coping with the inherent complexity of SDIs and reducing the costs of developing and maintaining SDI applications. Easier and more simple interfaces for spatial services or even data models might have a positive influence in all the requirements since services providing the functionality (publication, discovery, access and processing) might offer more flexible and easy ways not only to be invoked but also to be chained to complete complex workflows (Granell et al, 2012).

Public and private cloud infrastructures provide a means of automating the administration of the basic IT environment as well as SDI tools and applications deployed within this environment. This supports both the easy ad hoc deployment of SDI content offerings and high-end mission-critical solutions. The costs of achieving the level of service performance and reliability needed for the broad acceptance of SDIs will decrease significantly. Public authorities with weak IT infrastructures will be able to purchase infrastructure services tailored to their specific needs, which accelerates the process of deploying SDI content and implement applications on top of them. This trend might also have a positive impact in all the functional requirements since service providers can affordably offer a higher level of service now and spatial organizations can avoid to store and maintain hardware, which can be more efficiently managed in the cloud infrastructure.

Furthermore, the trend of deploying processing capabilities via processing services will increase the availability of functionality and decrease the need to maintain software locally. Cloud services will also support distributed processing capabilities in SDIs. This again, for simple fine-grained functions as well as for complex models, which require exceptional computational power. These processing capabilities will support the development of distributed quality-aware systems, which are capable of describing and handling the uncertainty of the information and the processing algorithms.

The publication requirement will be directly influenced by integrating user-generated content into the realm of SDIs. Web 2.0 describes the shift from a web of documents and users as passive consumers to a broader platform for communication, collaboration and business transactions, which strengthens the role of citizens as SDI stakeholders. Their demand for information and participation underpins the rationale of SDIs and hereby raises related priorities and budgets. Citizens are now able not only to consume but also to publish and contribute content to the information base of SDIs. Enabled through mobile
devices, sensors and crowdsourcing platforms, they collect, publish, share and continuously improve information, thus maintaining the SDI up to date. VGI becomes a multidisciplinary and valuable massive source of information at low cost, which complements the existing authoritative data sources in SDIs (Núñez-Redó et al., 2011). The sharing and availability of VGI within SDIs may substantially improve traditional geospatial analysis and decision-support tasks (Flanagan and Metzger, 2008; Pultar et al., 2009; Núñez-Redó et al., 2011). For example, Zook et al. (2010) has pointed out that VGI can provide “additional data at levels of granularity and timeliness that could not be matched by other means”. As a result, future SDIs will offer new types of geographic information, namely information including people’s experiences and perceptions. Furthermore, the timeliness of volunteered geographic information could help solve the challenge of real-time geosensor monitoring, as discussed below. Finally, since VGI enables citizens to be at the same time producers and consumers of geographic information, it is to be expected that the challenge of the “lack of awareness or importance of SDIs” identified by Williamson (2004) will no longer be an issue in future SDIs. Some authors (Budhathoki et al., 2008; Omran and van Etten, 2007) have already suggested a new SDI generation, largely influenced by these needs and the reconceptualization of the user role.

In contrast to the early days, when the development of SDIs primarily targeted G2G (Government to Governments) and G2B (Government to Businesses) communication, the changing role of individuals is creating a new set of concerns and priorities, such as improved search capabilities, open access to data, lightweight interfaces and tailored applications with adaptive and contextual user interfaces. This new group of users has its own concerns, which are extremely demanding, in terms of performance, accessibility and usability of information products. Their expectations and demands rise as offerings increase and they respond with increased attention and spending, which spurs on the further development and improvement of SDI capabilities.

Integrating the Sensor Web and the Web of Things (Section 3.5) in future SDIs requires new concepts and methodologies. The Sensor Web is already capable of making the functionality of sensing devices available within SDIs (Bröring et al., 2011). However, the integration of smart things into standardized web service architectures, such as SDIs, might be too costly and complex in practical applications (Mattern and Floerkemeier, 2010). New approaches are needed to combine the Sensor Web technology and Web 2.0 concepts to integrate aspects of the Web of Things with SDI. The technological trend and progress in sensors and mobile devices and the Web of Things might have an influence on SDI development in improving its dynamics and access to higher-resolution spatio-temporal data. However, some questions remain, such as which data (nature and scale) should be considered, which area should be sensed and how to manage dissemination and rights management (Goodchild, 2010).
The linked open data trend has the potential to be a game changer in the field of SDIs. The Web will increasingly be used to encode and interlink different kinds of information, and in turn to harmonize data models and vocabularies on-the-fly. The future web will actually be a composition of webs, where several paradigms are used to represent and process knowledge. From the author’s point of view, new patterns of the Web of Data, for providing and using spatio-temporal information, will complement and partially replace classic SDI patterns. New information resources will be integrated in the SDI by providing simple links, which can be used immediately to access information, and which employ automated crawling mechanisms to update cached views of the data and its metadata. This pattern will widely replace the traditional approach of publishing and registering content through standardized metadata catalogues, which is less flexible and more complex in terms of technical settings and workflows.

These new paradigms will also force the appearance of new and more sophisticated methods to discover and access content. Linked open data technologies will enable users to find data, enriched semantically, and access datasets which implicitly contain their descriptions, coming from different communities and linked together. These methods will allow both humans and machines to navigate through the data layer, by following links to the targeted and most appropriate data items.

One of the direct applications of the Web of Data is to increase the ubiquity of SDIs. Linked data methods facilitate the modeling and integration of information. This way, real world entities or things, can be augmented into “smart things”, being equipped with multiple capabilities, such as sensing, processing, memorizing and communicating spatio-temporal knowledge about their state and their environment. This phenomenon called the Web of Things will connect physical things such as cars, parcels, streets or buildings to SDI components. Smart sensors will be an essential part of SDIs, since they provide real-time access to live geo-information, which is needed to effectively monitor the environment.

5. CONCLUSIONS

The foregoing sections presented an analysis of the current status of SDIs, followed by a description of the main research topics in the field of geoinformatics and trends in mainstream IT. This section aggregates these findings into a set of hypotheses on the future development of SDIs.

5.1. SDIs will Continue to Evolve

On first sight, this hypothesis may seem trivial, but it addresses the recurrent discussion that SDIs may constitute a dead end, due to their complexity and slow
development (Béjar et al, 2009; Díaz et al, 2011). Why bother with special SDI arrangements when the Web is already providing its own sophisticated means of sharing and integrating heterogeneous resources. One answer is that SDIs are not only about technology. Agreeing on common policies, standards and organizational structures is essential for bringing these technologies into use, and thus, realizing their potential benefits. The classic definition of SDIs being a set of policies, technologies and institutional arrangements to assist user communities in collecting, sharing and exploiting geospatial information resources (Nebert, 2004; Masser, 2005) still proposes a valid set of requirements and a general means of achieving these goals. Its scope is broad enough to embrace even major shifts in its concepts and implementations.

5.2. SDIs will Benefit from Existing IT-Trends

SDIs are an integral part of the overall Information Infrastructure, driven by experts and stakeholders from the geospatial domain. While the overall II increasingly improves its capabilities in dealing with spatio-temporal information, SDIs will benefit from these developments. This will happen without delay, as far as no SDI specific standards or agreements are affected. The use of Cloud computing for example does not require any changes to SDI policies or institutional arrangements, and is already being increasingly adopted (Schaeffer et al, 2010; Moore and Parsons, 2011; Baranski et al, 2011).

The same is true of the publishing of public sector information, published in SDIs, based on standardized open data licenses, which will immediately result in better accessibility of spatial data for many purposes.

Other advancements, such as the development towards more lightweight interfaces, data formats and protocols, require moderate changes in SDI specific standards, which hinders their immediate adoption. Nevertheless, they can be regarded as low hanging fruit, since they are in line with the core architectural concepts of SDIs.

Emerging trends, like the Web of Data or the Web Of Things, are expected to be significantly adopted in mainstream IT within the next five to ten years (Gartner IT-Trends, 201110). This time is needed both for maturing the concepts and technologies and for growing the installed base. SDIs will contribute to this development, since their goals and requirements are part of the motivation that creates its momentum. The time needed for actually adopting these trends in terms of policies and technological standards depends on the adaptability of SDIs; this will be discussed in the next section.

10 http://www.gartner.com/it/page.jsp?id=1454221
5.3. Improving the SDIs’ Adaptability Accelerates their Development

SDIs are not driving mainstream technology, but they are unfolding their use in the geospatial domain by settling common policies, standards and institutional arrangements within certain user communities. As outlined in Section 2, this leads to a lower pace of development compared with mainstream IT.

Referring to the design principles for information infrastructures proposed by Hanseth and Lyytinen (2010), the adaptability of SDIs should be improved by employing certain strategies. The most important of these is to create choices, rather than to strictly define one stack of standards, which fixes the finest details of SDI building blocks. Choices represent degrees of freedom, and these will be used to implement variants, which have to prove their benefits in practice. The “survival of the fittest” principle will guide their further evolution, which will be more closely aligned with the development of the Geospatial Web.

5.4. Usability is the Key Driver for Leveraging the Installed Base

As stated in the first section, SDIs currently do not completely fulfill users’ expectations. Often, users are not able to find offerings which meet their requirements, while existing offerings are underutilized. As a consequence, SDIs are not sufficiently attracting users to invest their effort and participate in the maintenance of the SDI and its content. A strong focus on an SDI’s usability, both for providers and consumers of spatial information resources, would create significant momentum for self-reinforcing growth.

Referring to the set of requirements outlined in Section 4.1, an action plan for improving SDI usability, heading for short- and midterm improvements, should address the following aspects:

5.4.1. Easing the publishing and discovery of information resources

This may be achieved by providing users with mechanisms to facilitate the interaction and maintenance of the deployed resources (Díaz and Schade, 2011); these mechanisms should assist users in making web services first class resources of the web, following the linked data approach. This means providing a URI, which primarily identifies the web service, and links to both the service URL and to a richer service description, for instance using RDF encoded descriptions of the resource. Publishing would mean rendering the service plus its content and metadata accessible online, and placing some links in already-existing information resources. These do not have to be, but can be, dedicated SDI registries. This concept would enable search engines to automatically collect the metadata which is needed to enable potential users to find information resources of any kind.

Since linked data provides a universal model for encoding data and metadata and for seamlessly integrating data models, this would significantly ease the
integration of meta-information resources. Furthermore, it might be more attractive for commercial search engines to index geospatial content, since the resource provides human readable information.

5.4.2. **Improve the accessibility of geospatial data and services**

A first step should be to foster the provision of open data, since to do so would dramatically reduce transaction costs. Providers of information resources would be capable of simplifying their internal processes and technical setups. On the user side, this would enable further usages and significantly reduce the effort expended on evaluating, negotiating and contracting access conditions.

A second step should be to foster the integration of more simple service interfaces and data formats (such a REST-based interface) into SDI standards. This would reduce the cost of integrating and chaining information resources into various applications (Granell et al, 2012).

In the long run, more and more information resources should be provided in line with linked open-data methods, in which content and description are published in an integrated manner, thus increasing linkage to related resources and facilitating the navigation and discovery of the target resources. This would reduce the costs of integrating data from various sources and lead to a self-reinforcing process of harmonizing data models.

5.4.3. **Improving the performance and reliability of GI services**

Cloud computing should increasingly penetrate SDI environments, thus providing information resources at a high quality of service. The effect will be comparable to the effect that increasing bandwidth has on the usability of the web.

As far as information resources can be offered as open data, public commercial platforms can be used to serve data redundantly, which further increases availability and shares the costs of providing access to these resources.

5.4.4. **Supporting the development of user-driven applications**

The key to a broader offering of user-driven applications, which are tailored to the user's needs, is to cultivate an agile ecosystem of developers around SDIs. This can be achieved by easing access to high-quality information resources. Furthermore it should be leveraged by fostering the provision of raw data, which provides more degrees of freedom for software developers than interpreted data or map services.

Leveraging this agile ecosystem will in fact support a more user-oriented SDI, since it will accelerate the matching of demand and supply regarding the user's requirements and SDI resources.
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Is there a Future for Spatial Data Infrastructures?

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Abstract. This paper provides an account of the status of Spatial Data Infrastructures by today and an estimation of their future evolution by comparing with developments in other areas. The paper starts with the definition of spatial data infrastructures and summarises their implementation worldwide. The actors involved are examined. It is shown that developments of the Internet are challenging traditional Spatial Data Infrastructures. These are providing seamless data with new business models. The term “Neo-Geographics” or “Volunteered Geographic Information” has been coined for these developments; we call it collaborative geo-spatial web. Both developments, traditional spatial data infrastructures and collaborative geo-spatial, are compared to understand their similarities and differences. User demand is considered an important point. The hypothesis is put forward that spatial data infrastructures and web developments will converge together into something that we could call a knowledge infrastructure.

1 Spatial Data Infrastructures

Spatial data infrastructures aim at making spatial data accessible to all kinds of users. Spatial data are complex from a technical point of view since they are multi-dimensional, voluminous and require many special and time consuming methods for their analysis; many applications require a high degree of accuracy [Longley et al. 2001]. On the business side, they are expensive to create and methods for their access and distribution vary between producers and countries or are often unclear. The most widespread definition of a spatial data infrastructure is:

“A Spatial Data Infrastructure supports ready access to geographic information. This is achieved through the co-ordinated actions of nations and organizations .... These actions encompass the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the national and regional scale are not impeded in meeting their objectives.” [Masser, I., 2005, adopted from the Global Spatial Data Infrastructure Association website (www.gsdi.org)]
Meta data are an essential component of SDIs since they describe who has the data, what are their characteristics and the conditions for access and use. Data are normally accessed in searching a meta data catalogue available on geo-portals.

Following [Masser, I., 2005], spatial data infrastructures (SDIs) had a first milestone in 1986, more than twenty years ago. Since then, SDIs have attracted a lot of attention, many national, regional or local SDIs have been created, much SDI research is done. The European INSPIRE directive [Commission of the European Communities, 2007] in particular has strongly promoted the SDI discussion in Europe. Because of its legal character, it would be realized in all European Union member states, creating a European SDI.

Some authors distinguish two generations or phases of SDIs [Masser, I., 2005, and Williamson, I., et al. 2006]. The first generation is considered product based and focused on data. The second generation emerged around 2000; it is characterized by a process led model and driven by the needs of users. Sub-national governments and the private sector are said to have a greater influence on SDI development [Williamson, I., et al. 2006], since data relevant to people are produced there. The process model of this second generation emphasizes the steps or processes needed to create and execute an infrastructure and provides therefore a communication channel for knowledge infrastructure and capacity building [Rajabifard, A. and Williamson, I. P., 2001]. Further characteristics of this second generation are a shift towards implementation and to decentralized networks, which are a basic feature of the World-Wide-Web [Masser, I., 2005].

According to [Masser, I., 2005], the strengths of SDIs are the diversity of users to access a wide range of geo-referenced data sets, the integrating concept of SDIs, and its use of recent development in location based services, the Internet and the world-wide-web. The weaknesses result from the need for “data sharing on an unprecedented scale”, requiring different organizational cultures to work together, difficulties in achieving consensus and resulting limited commitment by stakeholders.

Lance [Lance, K.T., 2005] points to a further problem, which is identification of costs for SDI development, and which is often neglected or carried out on too general a level. INSPIRE has addressed this problem with its impact assessment. Both costs and benefits of INSPIRE implementation were estimated and it was found that the benefits outweigh the costs by at least six times [Masser, I., 2007]. Estimating these benefits had been rather difficult and an assessment has been done for public sector activities only [Dufourmont, H., 2004]. Gains by the private sector are mentioned by example, and it is admitted that benefits in terms of new products and services cannot be identified.
What is the status of SDI development today? According to [Rajabifard, A. and Williamson, I. P., 2001], the adoption of SDIs among spatial data communities obeys an S-shaped diffusion curve, referring to earlier research work. Such an S-shaped curve is often used for product adoption showing this adoption over time from inception via early adopters to late adopters and maturity. It may be interesting but difficult to position the current state of SDI development on such a curve, even impossible on a general level. The most detailed investigation of the state of implementation of SDIs has been done for Europe [Vandenbroucke, D., et al., 2008]. The conclusion of this report is that nowhere in Europe an SDI is fully realized. On the S-shaped curve, we could estimate that the early adopter phase is passed but that the late adopter phase is not yet reached. Masser [Massser, I., 2005(2)] describes several SDIs as being in the early majority phase, referring to a survey carried out by the global spatial data infrastructure (GSDI) association.

This raises the next question, why it takes so long to realize spatial data infrastructures, especially in considering the very high benefits estimated by the INSPIRE impact assessment. The answer may lie in their inherent complexity; the major barrier seems to be difficulties in transforming organizations which would be necessary for sharing data. Lance points out [Lance, K.T., 2005] that this required joint up approach is problematic from an administrative standpoint and calls it a “fundamental dilemma” of SDIs.

Looking at the diffusion of spatial information from an economic point of view, Krek and Frank [Krek, A., Frank, A.U., 2000] conclude that geographic data are not a standard economic good with the following characteristics:

- Geographic data are a non rival economic good;
- Geographic data lead to a natural monopoly;
- It is practically not possible to control the consumption of geographic data;
- Geographic data are an experience good.

They propose a value chain concept for the sequence of operations in the production, integration and transformation of geographic data as displayed in figure 1 below [Krek, A., Frank, A.U., 2000].

Figure 1: The Geo-information Value Chain, reproduced with permission of the author.
In order to understand the value chain in the context of SDIs, both the market of geographic data and the users – customers – have to be considered. Frank [Frank, A., 2008] distinguishes between two different markets for geographic data, each one with different structures: mass market and specialized market. The mass market uses a few common datasets, whose value increases by combining them with other information; business models are mainly advertisement based. The specialized market is completely different: only a few organizations participate using specialized data sets with a high value and cost. Accuracy of data, completeness and reliability are important.

Having defined the types of the market for spatial data or geographic information, it is important to understand who are the users or the customers in spatial data infrastructures. Vandenbroucke e.a. [Vandenbroucke, D., et al., 2008] define the stakeholder community in SDI as: developers, expert GI users, the broader user community; public authorities, academic and private sector, which is everybody. The authors however admit that very few stakeholders are ready for SDIs. Looking through the SDI literature and examples quoted, users mentioned are: public sector comprising government authorities or public companies, then services and software providers dealing with GIS. Craglia [Craglia, M., 2007] states that SDI would be used by experts only. Gould inquires critically about the usage of data as provided by SDIs [Gould, M., 2007]. He distinguishes between “GI professionals, who normally know what data are available and where … and the general public, who do not search for geodata but rather issue their queries to higher-level web applications”.

We conclude from these considerations that the end customer of an SDI is not the final user in figure 1 but rather the specialist, who is the last node in the value chain. Hence, the value chain is incomplete in the case of SDIs, and further determined by the value chain paradox [Krek, A., Frank, A.U., 2000]: under normal circumstances, the value of the information and the sequence of tasks in a value chain are defined by the user, which means from the end. In the case of SDIs however the end value is determined by the high fixed costs of data collection that occur in the beginning of the value chain.

As a summary of the above considerations, we conclude:
1. Much conceptual and research work has been done for SDIs, and implementations of SDIs have started. Maturity and general acceptance of SDIs have however not been reached, although SDIs are in their second generation. Major difficulties are the need for reorganization and a resulting lack of motivation to implement SDIs.
2. Stakeholders participating in SDI development are mostly public sector administrations. Participation by the private sector or by citizens is rare
and their benefits are indirect only. Craglia calls an SDI such as INSPIRE a government to government initiative [Craglia, M., 2007].

3. There is a lack of awareness of SDIs. Direct participation requires a high level of expertise. Use of SDIs beyond the specialist community is limited.

4. SDIs are operating in a specialized (or niche) market and are not designed for the mass market. The value chain is incomplete and the related value chain paradox, along with the special characteristics of spatial data, constitutes a basic difficulty for SDIs from an economic point of view.

2 SPATIAL DATA AND THE WORLD-WIDE-WEB

The World Wide Web has after its creation in 1989 quickly become a tool to display maps and related services. One well-known early example is Mapquest; in Bulgaria, bgmaps.com has become a universal tool to find a location in the country. More recently, some sites have attracted much attention, such as Google maps, Yahoo! Local Maps and Windows Live Local. “Google maps” or “Google Earth” was made available in 2005 and is considered a breakthrough in availability and easy use of geo-spatial data. Recent developments would not have been possible without new technological innovation. Advances have been made in capturing images of the earth via high resolution digital cameras and in the production of true orthophotos from aerial photographs or satellite images. Cameras mounted on airplanes achieve a ground sample distance of 20 cm, the latest satellites (World View) of 50 cm [Konecny, G., 2008]. Those images are produced by private companies, not any more by the public sector. Possibilities of 3D modeling lead to unprecedented possibilities to present our world. The World-Wide-Web has undergone a new revolution with Web 2.0, providing completely new ways of sharing information and communicating, quickly taken up by the public. The open source community drives many of these new developments, and standards play an important role.

The widespread availability of GPS coordinates in particular contributed strongly to the use of maps and location referenced information by the Internet audience. Now it is possible to geo-reference any type of information and distribute or share it via the Internet. [Erle, S., Gibson, R., Walsh, J., 2005] call this geocoded hypermedia and predict a big disruptive innovation. A new research area was born, which some call Neo-geographics, others Volunteered Geographic Information (VGI) [Goodchild, M. F., 2007]; we call it here the collaborative geospatial web. Google maps as one of the first sites providing maps of the whole globe offered an API to access the maps and many mash-ups were created using
these maps. Web sites were developed allowing users to create and edit maps; OpenStreetMap is a prominent example. Maps are easily combined with other content and tools from various sources, so-called mash-ups, commonly called part of the Web 2.0. Tools are created that make mash-ups available even to non-programmers such as Yahoo! Pipes (http://pipes.yahoo.com). Mash-ups link into social networking sites. The difference between geo-spatial data, considered by many as very complex, and other content becomes blurred; some Internet content just adds location in order to get to a place on the earth; Geo-RSS is an example.

The geo-spatial semantic web develops ontologies for geo-spatial data with the goal to increase understanding of such data by machines. Metadata as a tool to find spatial data are not a topic; maps are simply available, being rather a means to get to other information such as specific features on the earth, hotels, restaurants, businesses and others. As this author pointed out in earlier papers [Boes, U., 2006 and 2007], maps and use of maps was made easy, to the reach of the masses, opposed to GIS, which is a specialist tool.

This Internet driven use of spatial information is a mass market phenomenon, driven by the community of Internet users who do not have deep knowledge of geography. Providers are private sector companies, and business models are clearly established; in most cases costs are paid by revenues from advertisement. Comparing the process again with the value chain model proposed by [Krek, A., Frank, A.U., 2000], we recognize that all steps of the whole value chain are included. In this case, the total value as also the costs of the processing steps are determined by the users’ needs and not by the fixed costs of producing the raw material, which is the spatial data. On the S-shaped curve, we would position these developments somehow around or before the early majority.

These developments have of course also been noticed by the SDI community. [Masser, 2005] considers it as a strength of the SDI concept that is includes recent developments of the Internet and location based services. However, he is also concerned “that the GI/SDI sector will be swallowed up by these broader debates and lose its identity in the process. As a result some of the special qualities of geographic information may not be adequately considered in future applications.” These “broader debates” he refers to are those related to Information Society aspects and the digital revolution, as well as discussion around public sector information as for example manifested in the EU’s Public Sector Information Directive. He did not explicitly mention the geospatial web as a threat.

Some national mapping authorities follow these developments very closely; one main example is Ordnance Survey of the United Kingdom. Vanessa Lawrence, Director General and Chief Executive Officer of the
British Ordnance Survey said in an interview at the AGI conference in Stratford-Upon-Avon [Thurston, J., 2007] that Ordnance Survey strives to meet the needs of those people as well who are involved in mashups and data sharing. Ordnance Survey had developed their own API to access Ordnance Survey mapping data, called Open Spaces, which due to legal restrictions never made it to the market.

3 CONCLUSION: THE FUTURE

Two different worlds for the diffusion of spatial information seem to exist: one traditional geo-spatial world created by the public sector as data provider, where spatial data infrastructures are the dominant theme; a second one where the Internet community makes data available, driven by the private sector with obvious business interest. Both seem to be independent of each other, and the question arises where this will lead to – to the prevalence of either or the merging of both.

SDIs are created by specialists for specialists with the goal to make diverse and heterogeneous spatial data available and accessible; the major tool used in an SDI is a GIS. SDIs can be considered as a top down approach [Gould, M., 2007]. The Internet and the World-Wide-Web have become the main tool to supply spatial data via meta data.

On the other hand, the Internet community, mainly pushed by the availability of GPS coordinates has added location to its content. Mash-ups have made it possible to combine satellite images or digital maps and geo-referenced content. Geo-referenced content is created and made available by users in the mass market in an easy way. This is a bottom-up approach, contrary to the development of SDIs. We further observe that provision of location based content goes much beyond traditional paper based maps in offering access to 3-D views, video and other multimedia content.

The following table 1 is an attempt to contrast important characteristics of SDIs and the collaborative geospatial web, which admittedly provides some simplified view.

Contrasting the two different approaches or worlds, the question for the future arises inevitably. There may be three different scenarios:

- Both approaches will continue to develop and exist independently;
- One approach will continue to develop independently with the other one disappearing;
- One approach will submerge the other one and consequently both will merge.
Table 1: Tabular comparison between SDIs and the collaborative geospatial web.

<table>
<thead>
<tr>
<th>Category</th>
<th>Spatial Data Infrastructure</th>
<th>Collaborative Geospatial Web</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value chain</td>
<td>Public Data Producer → Specialist</td>
<td>Private Data Producer → End user</td>
</tr>
<tr>
<td>Major Stakeholders</td>
<td>Public Sector</td>
<td>Private Sector, Internet Users</td>
</tr>
<tr>
<td>Revenue model</td>
<td>Cost recovery (varies between countries)</td>
<td>Advertisement, affiliate</td>
</tr>
<tr>
<td>Content</td>
<td>Spatial Data</td>
<td>Geocoded Hypermedia</td>
</tr>
<tr>
<td>Technology</td>
<td>GIS, Web Portals</td>
<td>Web 2.0 tools</td>
</tr>
<tr>
<td>Competition</td>
<td>Low (natural and legal monopoly)</td>
<td>High</td>
</tr>
<tr>
<td>Major Strength</td>
<td>Existence of data sets</td>
<td>Uptake by industry and users</td>
</tr>
<tr>
<td>Major Weakness</td>
<td>Need for re-organization</td>
<td>Unfit for mission critical applications</td>
</tr>
</tbody>
</table>

In order to be able to answer the question, we need to consider that SDI development has a strong organizational component and is public sector oriented. The geospatial web is not organized but is pushed by technology. Research areas such as the geospatial semantic web are followed by both areas. One important argument is that solutions needed by users focus on all kind of content integrated into the solution and the work flow, with location as one component. This will eventually lead to treating geo-spatial data as any other content. The concept of a map will have to be revised as a model of the human’s mind of places on the earth. Traditional GIS, along with specialized data sets and meta data, will remain the realm of some specialized applications only. The hypothesis is put forward that spatial data infrastructures and web developments will converge together into something that we could call a knowledge infrastructure. Spatial data infrastructures as an area of itself will cease to exist, and we agree to the concern by Masser [Masser, I., 2005] that the GI/SDI sector might lose its identity.

SDI stakeholders should consider completing the value chain for providing spatial data and think about different, new business models so that their spatial data can be made available to end users. They have to acknowledge the existence of the collaborative geospatial web and achieve stronger collaboration with the geo-spatial web. Some have already started this collaboration as the example of Ordnance Survey shows.
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Multi-view SDI Assessment Framework

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Abstract
When developing Spatial Data Infrastructures (SDI) initiatives it is increasingly important to assess their outcomes in order to justify the resources spent on those infrastructures. Many researchers throughout the world have been struggling with the issue of assessing SDIs. The task is difficult due to complex, dynamic and constantly evolving nature of SDI. As SDI can be treated as a Complex Adaptive System, the assessment should include strategies for evaluating those kinds of systems. One strategy is to use multiple assessment approaches and methods. The general evaluation research and experience provide additional motives for adopting such a strategy. We present the multi-view framework for assessing SDI initiatives around the world, and argue that the strength of this assessment design lies in its flexibility, its multidisciplinary view on SDI and a reduced bias in the assessment results. The multi-view framework contains methods that not only evaluate SDI performance, but also deepen our knowledge about SDI functioning, and may assist in its development. The article presents the assessment framework and describes its theoretical grounding in complexity theory and evaluation research. The application of the framework is beyond the scope of this paper.

Keywords: Spatial Data Infrastructure, Assessment framework, Evaluation, Complexity

1. INTRODUCTION

Over the last few years Spatial Data Infrastructures (SDIs) have become an important issue in Geo-Information Science, its significance was demonstrated by numerous initiatives all over the world at global, regional, national and local levels. The growing number of clearinghouses may be a good indicator for the development of Spatial Data Infrastructures. According to Crompvoets (2006) the...
number of national SDI clearinghouses increased rapidly from the first initiative in 1994 in the USA to 83 national clearinghouses in April 2005. Large sums of money have been invested into SDI initiatives over the last few years. Worldwide around €120 million is spent each year just on clearinghouse management (Crompvoets, 2006). The investment requirements for an Infrastructure for Spatial Information in the European Community (INSPIRE) at European, national, regional and local levels are estimated to be from €202 to €273 million each year (INSPIRE, 2003). Given this expenditure and society’s interest in the proper and effective use of public funds, it is imperative that these SDI initiatives should be assessed (Shadish et al., 1991). SDI assessment is an increasingly hot topic because SDIs are mainly established by governmental bodies and resourced from the public funds, and the demand for such research is increasing. For example, implementation of the European directive establishing an Infrastructure for Spatial Information in the European Community will require monitoring and regular reporting of the implementation of the Directive as well as reporting on the use and the (positive) impacts of the infrastructure (European Commission, 2007).

Many researchers have tried to assess SDIs (Crompvoets, 2006; Steudler et al., 2004; Rodriguez-Pabon, 2005; Delgado-Fernandez and Crompvoets, 2007; Delgado-Fernandez et al., 2005; Kok and van Loenen, 2004; Masser, 1999; Onsrud, 1998; SADL, 2005). All these attempts, however useful and valuable, either concentrate on one aspect of SDI (Crompvoets, 2006; Delgado-Fernandez et al., 2005), or are bounded by one region (SADL, 2005), or describe SDI development in few particular countries (Masser, 1999; Onsrud, 1998), or are still conceptual in nature (Kok and van Loenen, 2004; Rodriguez-Pabon, 2005; Steudler et al., 2004). What is needed is a multidisciplinary framework that could evaluate the full extent of SDIs worldwide.

Assessment and evaluation of SDI initiatives is problematic for a number of reasons. Even within the SDI community there are differences in the understanding of SDI and its potential benefits. Craglia and Nowak (2006) raise this issue when reporting on the key findings of the International Workshop on SDI’s Cost-Benefit. They argue that there is much confusion resulting from the lack of an agreed definition of SDI, its components and the relationships between them. Moreover, different studies on SDI assessment identify different benefits and assign them to different categories. Similar conclusions are formulated in the report of the workshop ‘Exploring Spatial Data Infrastructures’ (Grus et al. 2006a). This makes it difficult to identify uniform criteria of merit for SDI inputs, utility, outputs and outcomes. SDI is also difficult to assess because of its complexity and dynamic and constantly evolving nature. SDIs also differ between countries as the same implementing rules may cause different results. For example, at the European level, the INSPIRE directive lays down general rules for establishing an SDI for the European Community (European Commission, 2007). Nevertheless, despite the fact that SDIs in the member states will behave
and operate in a similar general way as indicated by the directive, they will never be the same, and sometimes will differ considerably depending on political, economical and cultural national circumstances. The directive acknowledges this diversity and assumes that INSPIRE will be build upon SDIs that are established and operated in member states.

In this paper we try to build a coherent SDI assessment framework that acknowledges this complexity. First we identify and analyse the key SDI characteristics that underlie the dilemmas affecting the assessment strategy. To deal with these dilemmas we examine SDI through the lens of Complex Adaptive Systems (Grus et al., 2006b). From this analysis we construct an assessment framework based on the principles of evaluating Complex Adaptive Systems (Eoyang and Berkas, 1998; Cilliers, 1998; De Man, 2006b) and evaluation theory applying to multiple-approach evaluation, using existing SDI evaluation approaches.

In section 2 we introduce the key characteristics of SDIs that influence the way in which SDI should be evaluated: multi-definitions, multi-objectives, complexity and dynamism are the issues of interest. Section 3 presents the theory of Complex Adaptive Systems (CAS) and its assessment issues, with a discussion on the issue of using multiple approach strategy in general evaluation practice. Section 4 presents the prototype evaluation framework for SDI infrastructures. The article closes with a discussion, conclusions and recommendations, especially on the potential difficulties with applying the framework. We do not discuss the drawbacks or benefits of the particular approaches as these will become evident after use of the framework.

In this paper we use several terms regarding the evaluation domain. For clarity, we explain the following terms used in the text:

- SDI assessment framework – a construct of various assessment approaches and methods built around CAS assessment principles and general assessment theory to structure and organize SDI evaluation.
- Assessment purpose or perspective – one of three main purposes or perspectives for performing an assessment: accountability, knowledge and development.
- Assessment approach – whole methodology of assessing particular SDIs from a certain viewpoint, e.g. SDI development, clearinghouse, or performance.
- Assessment methods – the techniques used in SDI assessment approaches to collect indicators. They include different types of surveys such as questionnaires and web surveys, document studies such as country reports, key informants having unique knowledge related to the issue being evaluated, such as SDI coordinators, and case studies (Frechtling and Sharp, 1997).
Whenever the terms ‘evaluation’ and ‘assessment’ are used, they both refer to the characterization and judgement of the merits of SDI.

2. SDI NATURE AND ASSESSMENT ISSUES

Assessing SDI, especially in worldwide comparison or benchmarking studies, remains problematic. The reason for this might be the nature of SDIs, particularly their multifaceted and dynamic nature, complexity and vaguely defined objectives. Hansen (2005) stresses that the characteristics of the evaluated object determine the choice of the evaluation models. Therefore, before proposing the SDI assessment framework, it is necessary to explore these SDI characteristics in more detail to enable a justification of the choice of the assessment strategy.

SDI is defined in multiple ways. For example, Chan (2001) collected the 11 most popular SDI definitions by different organizations and authors in different parts of the world at different times. Each of these definitions describes SDI from slightly different aspects and none of them describe SDI completely. The variety of ways in which SDI is defined reflects its multifaceted character (De Man, 2006). Rajabifard et al. (2002) claim that some SDIs may be treated as products while others as processes, which raises fundamental questions about SDI evaluation. To be able to assess and compare the objects of the evaluation, an agreement must be reached on single definitions of these objects and about criteria and values of merit. Referring back to Rajabifard’s classification, are we assessing SDIs as products in terms of their structure or the processes they should facilitate? The criteria and values of merit may therefore depend on how we understand the SDI concept.

It can be stated that the conceptual objective of Spatial Data Infrastructure is to enhance access to and the sharing of spatial data produced by various agencies. The principal purpose of SDIs may be defined in different ways, for example: ‘let geographic information promote economic development, improve our stewardship of natural resources, and protect the environment’ (Clinton, 1994); ‘to help avoid fragmentation, gaps in availability of GI, duplication of data collection and problems of identifying, accessing or using the available data’ (SADL, 2003); and ‘to support information discovery, access, and use of geographical information for example in crime management, business development, flood mitigation, environmental restoration, community land use assessment and disaster recovery’ (Nebert, 2004). Different countries do not define the objectives of their SDI in the same way. Some stakeholders may only accept the facilitating of data exchange role of SDI; others may see SDI only as a facility for spatial data production and storage. To allow the worldwide benchmarking of SDI, we will need a uniform definition of the objectives of SDI, but the variety of interpretations of what SDIs are suggest that it will not be possible to find a single definition of SDI that everybody will agree on.
This means that the framework should be able to incorporate different understandings and views of the objectives of SDIs.

During the workshop on Exploring SDI held in Wageningen in January 2006, **SDI complexity** was indicated as being one of the main obstacles and challenges to its evaluation (Grus et al., 2006a). The complexity of SDI is due to the dynamic and non-linear interactions between its entangled components. Chan and Williamson (1999) state that its functionality becomes more complex over time as new SDI requirements emerge and are adopted by the users. As an SDI model moves from being data-centric to service-centric, complexity increases and identification and measurement benefits become more problematic (Georgiadou et al., 2006). This means that the nature of SDI and the interactions between its components cannot be described in a simple and uniform way. Moreover, SDI has a different character and works in a different ways in different parts of the world. This complexity of SDI makes it difficult to implement in diverse environments in the same way and with the same results, which in turn makes assessment difficult because of the problems of attributing success or failure of SDI implementation to one or more concrete factors. In other words, because SDIs are complex it is difficult to track cause-and-effect relationships (Rodriguez-Pabon, 2005).

The dynamic nature of SDI is reflected in the intensive flow of information between data producers and users (Masser, 2005). According to Rajabifard et al. (2003b) and Chan (2001) the dynamic nature of SDIs is reflected in changes in SDI technology, people and their needs. As SDI requirements and expectations change, the mediation of rights, restrictions and responsibilities between people may also change. Such changes imply that the system’s behaviour is unpredictable, which presents a challenge for assessment practice. The assessment framework should allow assessment practitioners to detect and analyse the predictable as well as the unpredictable changes. Another aspect of the dynamic nature of SDI dynamism is its evolving nature. Most assessment practices measure SDIs at one moment in time, but the SDI assessment framework should also be able to describe its evolution over time, for example through longitudinal assessment approaches.

3. **TOWARDS THE ASSESSMENT FRAMEWORK**

There is strong evidence that SDIs behave like Complex Adaptive Systems (CAS) (Grus et al, 2006b), and the principle of evaluating Complex Adaptive Systems (Eoyang and Berkas, 1998) underpins the design of the SDI assessment framework. Complex Adaptive Systems are open systems in which different elements interact dynamically to exchange information, self-organize and create many different feedback loops, in which relationships between causes and effects
are non-linear, and where the system as a whole has emergent properties that cannot be understood by reference to the component parts (Barnes et al., 2003). Analyses of the structure and behaviour of Dutch, Australian and Polish SDIs indicate that the SDIs share the same behavioural characteristics as CAS (Grus et al., 2006b). We therefore decided to use the principles of evaluating Complex Adaptive Systems for SDI assessment. These principles specify that the framework should be flexible and have a structure that permits frequent reconsideration and redesign, because the baseline (understanding, definition, and objectives) of CAS (and also SDIs) is constantly changing. The assessment programme should concentrate on both the expected and unexpected system behaviour. It should also capture long-term and short-term outcomes, from close and distant points of view: it should contain more general, regional or cross-national comparisons (distant view) as well as more detailed case study analyses of national or local SDIs (close view). At national and regional levels, the scale of the SDI dramatically affects the amount of detail that can be accommodated in the assessment. Wider national or transnational initiatives (e.g. worldwide assessment of benchmarking) require the involvement of a much broader stakeholder network, many more assumptions (not all of which will be accepted by all stakeholders) and much less specificity than local initiatives. Because of the complex interconnections, assessment programmes should include multiple strategies and approaches, including those for linear systems, and a variety of data should be collected to reflect the variability and complexity of the system. The assessment framework should also contain methods that can capture the patterns of causal relationships. But because these patterns of causation can change in CAS (SDIs) it is essential to capture the baseline (reference point) of these causal relationships (Eoyang, 1998). For example, it may be helpful to describe the relations between the five standard SDI components (people, standards, technology, policy and data) and then observe the emergent patterns, changes and evolution of these relationships. Detailed analyses of case studies may help to reveal these interactions and rules of causation.

The recommendations for complexity assessment given above are in line with Cilliers’ (1998) analysis that truly complex problems can only be investigated using complex resources. This is a reinterpretation of the antireductionist position that a complex system cannot be reduced to a collection of its basic constituencies (e.g. SDI components) – not because the system is not constituted by them, but because too much of the rational information gets lost in the process. In the same way, the SDI assessment strategy must also be complex if it is to represent the system’s variability and richness in information important from the assessment perspective. Accordingly, different assessment approaches and methods must be used simultaneously. This is also in line with De Man (2006b), who states that a multifaceted view is needed to understand concrete SDI initiative. The assessment framework should not try to capture and control complexity, but acknowledge multiple SDI realities shaped by heterogeneous and
reflective actors. At the same time, it must be a manageable tool that contributes to a better understanding and assessment of the processes connected with SDI.

If we agree that SDIs are complex systems the discussion above implies the use of rather complex and multiple assessment approaches and methods would be a valid approach to assessing or analysing these complex systems (see Eoyang and Berkas, 1998; Cilliers, 1998; De Man, 2006b). It is interesting then to analyse the experience and practice of evaluation theory and research with multi-approach and multimethod assessment models. In other words: what does evaluation/assessment research says about multimethod assessment?

Scriven (1983) stresses that ‘evaluation is a multiplicity of multiplies’ in a number of ways: ‘Evaluation is multfield, concerned with programs, products, proposals, personnel, plans, and potentials; multidisciplinary; with multidimensionality of criteria of merit; needing multiple perspectives before synthesis is done; multilevel in the “wide range of levels of validity/cost/credibility among which a choice must be made in order to remain within the resources of time and budget” and in the different levels of analysis, evidential support, and documentation appropriate in different circumstances; using multiple methodologies, multiple functions, multiple impacts, multiple reporting formats: “Evaluation is multiplicity of multiples”’ (Scriven, 1983). This multiplicity of evaluation is in line with the characteristics of SDI mentioned above: its multifaceted nature, the multiple purposes of evaluation, multiple definitions and multiple objectives.

Assessment of the multiple dimensions of the assessed object is also epistemologically motivated. The more vantage points that are taken, the better the constructed picture of truth will be. For example, the reality might be that one particular SDI has a very well developed clearinghouse, but an inadequate legal framework for access policy. In such cases, assessing only the access network (clearinghouse) of this particular SDI would draw a false picture of reality. Using multiple evaluation models also reduces potential biases in evaluation (Shadish et al., 1991) in case some methods generate considerably different results than others.

The multi-approach and multimethod assessment strategy is well recognized by evaluation practitioners. Datta (1997) confirms moderately high to high acceptance of mixes of methods, analysis and data in evaluation practice, but the difficulty of defining the quality of such multimethod studies should be recognized. Using multiple analyses (descriptive analysis and various statistics within one evaluation) is highly acceptable, although the need to deal with the biases inherent in different techniques is borne in mind. Using multiple data is also highly acceptable, as long as due consideration is given to the weighting of different data sources. Based on Datta’s evaluation experience, the benefits of using
multimethod analysis seem to be depth, methodological equity and transparent findings from all methods.

Assessments are made for many specific reasons, for example to measure and account for the results and efficiency of public policies and programmes, or to gain explanatory insights into social and other public problems, or to reform governments through the free flow of evaluative information (Chelimsky, 1997). Chelimsky (1997) distinguishes three general classes of evaluation purposes that cover all of the specific purposes: the accountability purpose of evaluation, the developmental purpose of evaluation, and the knowledge purpose of evaluation. Accountability evaluation measures the results of the programme by asking cause-and-effects questions. The developmental class comprises strategies to measure and recommend changes in organizational activities and to monitor how projects are being implemented across a number of different sites. The purpose of knowledge evaluation is to generate a better explanation of the programme or to acquire a more profound understanding in some specific area or field (Chelimsky, 1997). These three classes of purposes are not mutually exclusive with regard to methods, but they may be needed at different times. For example, evaluation for knowledge or evaluation for development may be needed before evaluation for accountability. Georgiadou et al. (2006) present a different taxonomy of evaluation purposes. They classify existing SDI evaluation approaches through a taxonomical lens from information systems evaluation research and explore four types of evaluation approaches: control, learning, sense-making and exploratory approaches. In principal, Chelimsky’s and Georgiadou’s classification are comparable. Control evaluation and Chelimsky’s accountability approach ask questions about achieving the goals of the programme. Georgiadou’s learning and exploratory evaluation and Chelimsky’s knowledge approach set out to learn and create knowledge about the assessed phenomena. Both Georgiadou’s sense-making evaluation and Chelimsky’s developmental evaluation aim to modify and improve the evaluated phenomena.

For the purpose of this paper we will use Chelimsky’s three classes: accountability, knowledge and developmental, as they originate from the evaluation theorists and seem to be more generic.

All the purposes of evaluation described above are valid for SDI assessment. There is a demand for accountability evaluation (Lance et al., 2006) to justify and monitor in a systematic way the relations between the investments in SDI initiatives and the results obtained. The assessment approaches that fall into the accountability class may help to answer questions such as did the use of spatial data increase as a result of implementation of a more liberal access policy to spatial data, and what is the impact of implementation of new SDI agenda on stakeholders’ activities? Questions about the efficiency and effectiveness of various SDI activities are also valid for accountability approaches. Developmental
evaluation is needed to monitor the transitions of SDI initiatives, such as transition through generations described by Rajabifard et al., (2003a). The analysis of the development, transitions and changes of SDI may help to capture and better understand its dynamic nature, and in monitoring whether SDI is being implemented according to the intended direction and recommend ways of SDI development. The primary functions of the developmental assessment approaches should be to measure and recommend changes in SDI activities and development, to monitor in a continuous way how SDIs are being implemented across many countries, and to find out whether SDI implementation is being realized according to the agenda. Knowledge evaluation is crucial for a better understanding of the mechanisms and forces behind SDI. Better understanding of the mechanisms and rules behind SDI frameworks allows action to be taken to improve them. ‘Once one understands the nature of the evaluand (evaluand = object of the assessment), one will often understand rather fully what it takes to be a better and a worse instance of that type of evaluand. To exemplify, understanding what a watch is leads automatically to understanding what the dimensions of merit for one are – time-keeping, accuracy, legibility, sturdiness, etc.’ (Scriven, 1980). The assessment of SDI could therefore contribute significantly to increasing our knowledge about the key qualities of SDI. The need to better understand the ideas and mechanisms behind SDI is also stressed by Georgiadou et al. (2006), who argue that more attention should be paid to conducting exploratory evaluations of SDI.

The remainder of this paper will focus on the presentation and description of the prototype framework, which acknowledges and deals with the SDI assessment issues discussed above.

4. MULTI-VIEW SDI ASSESSMENT FRAMEWORK

The previous sections justified the use of multiple assessment approaches, considering the multifaceted and complex nature of SDI. This section presents the assessment framework that potentially fulfils all of the requirements mentioned in the previous paragraphs. A multi-view framework is proposed in order to assess SDI. Figure 1 presents the conceptual model of the framework. The main idea behind the framework is that it covers all three purposes of assessing SDI: accountability, knowledge and development. It also acknowledges the multifaceted character of SDI.

The core of the proposed assessment framework is represented by the multiple assessment approaches that focus on different SDI aspects (facets). To overcome the problem of multiple definitions, SDI is treated here as a complex system with multiple facets. Because we concentrate here on SDI assessment, the facets are related to the assessment approaches included in the framework. Each approach treats SDI from different view. Principally, we concentrate only on the specific
objectives for each approach that SDI should meet in order to be good. For example, the Clearinghouse Approach concentrates only on the SDI’s data access facility; for this approach the objectives of good SDI are related only to data access technology. The essence of the multi-view framework is that it accepts multiple views on SDI and thus accepts its complexity in terms of multiple definitions. Moreover, each approach covers at least one of the three purposes of the assessment: accountability, knowledge and development. All approaches use one or more assessment methods, such as case studies, surveys, document analysis, etc., to evaluate SDIs. The proposed assessment methods are both qualitative and quantitative.

Figure 1: Multi-view SDI assessment framework

The Generational Approach is based on the generational development of SDIs described by Rajabifard et al. (2003a). The worldwide development of SDI can be measured according to the identified indicators of first, second and future
generations of SDI development. The results of such an assessment will help the
countries concerned to position themselves on the worldwide arena and to indicate
directions for future development. Moreover, iterative and longitudinal application of
the Generational Approach can measure the dynamics of the worldwide
development of SDI initiatives. The measurement of transitions through
generations may help to capture the factors that strengthen or weaken the
development of SDIs. The generational assessment approach falls into the
developmental class of evaluation. It seeks to answer questions about setting a
developmental agenda for SDI development, how to measure changes and to
monitor SDI implementations across a number of countries. The knowledge
purpose is also valid for the Generational Approach. Questions like why one SDI
implementation scheme works in Europe but not in Africa may be also answered
by this approach. In this approach the worldwide survey and document study may
be used to collect data.

The Programme Evaluation approach emerged from the burst of social
programmes in 1960s in the USA. The basic function of Programme Evaluation is
to check the accountability of social programmes launched in the education,
income maintenance, housing, health and criminal justice sectors (Shadish et al.,
1991). The Programme Evaluation approach can be defined as a determination of
the worth of any enterprise (programme) that aims at solving a particular problem
or improving some aspects of the area of interest (Worthen, 1990). This approach
treats SDI as a public programme aimed at improving the access to and the
sharing and usability of spatial data. Various sub-approaches can be distinguished
to conduct a Programme Evaluation. Worthen (1990) identifies a Performance-
Objective Congruence Approach, a Decision-Management Approach, a
Judgement-oriented Approach, Adversarial Approaches and Pluralist-Intuitionist
Approaches. One technique for analysing programmes might be to build a logic
model consisting of information on inputs, activities, outputs and outcomes. For
each of these components a set of indicators can be found to assess the
performance of SDIs. The Programme Evaluation approach falls into the
accountability and knowledge purposes of the assessment as it answers the
questions of whether the programme works and increases our knowledge about its
components. Case studies mixed with surveys are the most common method of
conducting a Programme Evaluation.

The SDI-Readiness Approach is an existing model that assesses whether a
country is ready to embrace SDI development (Delegado-Fernandez et al., 2005;
Delgado-Fernandez and Crompvoets, 2007). When building an SDI readiness
index, various factors like organization, information, access network, people and
financial resources are taken into account. Each of these factors consists of a
number of indicators that can be quantitatively measured. This model falls within
the knowledge and developmental evaluation purposes. The results can be used to
answer questions about comparing the progress made with implementing SDIs by
different countries. It also helps to identify obstacles in SDI programmes implementations. SDI-readiness is measured by collecting and analysing predefined indicators based on surveys.

The Cadastral Assessment Approach was originally developed as a land administration evaluation framework by Steudler et al. (2004). It presents a number of indicators for five areas in evaluating Land Administration Systems (LAS): the policy level, the management level, the operational level, influencing factors and assessment of performance. The reason for including this approach in the SDI assessment framework is that there are significant similarities between efficient and effective SDIs and Land Administration Systems and therefore there is a strong ground for using LAS evaluation and performance indicators for SDIs (Steudler 2003). However, this approach is still a conceptual one and has not even been used for evaluating LASs. It still needs to be developed and operationalized for application in practice. If applied it may give us answers about the performance of SDIs, as it contains a number of performance assessment indicators (accountability purpose of evaluation), and increase our knowledge about the policy, management and operational levels of SDIs (knowledge purpose of evaluation). The survey method will be used to measure predefined indicators on a worldwide scale.

The Organizational (Institutional) Approach is based on Kok and van Loenen’s (2004) research into the assessment of the different stages of development of geographic information infrastructures, when viewed from the institutional (organizational) perspective. This approach focuses on measuring the development of the following GII (SDI) aspects: vision, leadership, communication, self-organising ability, awareness, financial sustainability and status of delivery mechanism. This approach falls into the developmental perspective of evaluation as it measures SDI development from an organizational (institutional) perspective. So far, the authors of this approach have measured and analysed the development of five SDIs using the case study method (van Loenen, 2006).

The Performance-Based approach uses the Performance-Based Management (PBM) technique to evaluate, demonstrate and improve the performance of SDI (Giff, 2006). This approach is based on the assumption that SDI is an infrastructure and that methods like PBM normally used for assessing the performance of infrastructure can be used for assessing SDI. This method aims at developing performance indicators based on specific SDI objectives, which are used to measure the effectiveness, efficiency and reliability of SDIs. This approach is still in the conceptual stage and specific indicators and methods to measure them have yet to be developed. It falls under the accountability evaluation purpose as it mainly seeks to answers questions about SDI efficiency and results.
The Clearinghouse Suitability Approach is based on research by Crompvoets et al. (2004) into measuring and assessing the development of National Spatial Data Clearinghouses worldwide. A method for measuring a specific set of quantitative indicators of clearinghouse portals can be applied as a continuation of longitudinal studies started in 2000. This developmental assessment aims at showing the advances and trends in the development of clearinghouses (and web portals). This assessment approach uses survey (website visit) and contacting key informants to measure indicators of the development of clearinghouse and web portals.

The State of Play Approach is a study covering the period from mid 2002 to 2007 to describe, monitor and analyse activities related to National Spatial Data Infrastructures in 32 European countries: 25 EU member states, 3 Candidate Countries and 4 EFTA countries. The major activity of this study is to collect and structure all the relevant information on the status of the six building blocks that together, according to this approach, constitute an SDI: the legal framework and funding, reference data and core thematic data, metadata, access and other services, standards, and thematic environment (SADL, 2005). The same approach and methods can be used as a component of the multi-approach framework, also in regions of the world outside Europe. Document studies (country reports), surveys (website visits) and contacting key informants (national SDI experts) are the methods used in this approach.

Pabon (2005) present a theoretical framework to assess SDI initiatives by identifying and describing common success criteria across different contextual backgrounds. According to this framework, SDI initiatives must be evaluated in their two major dimensions: the quality dimension and virtue dimension. The quality dimension covers the efficiency and effectiveness of technical and organizational aspects of SDI projects. The virtue dimension consists of political, human and social aspects, which are measured against predefined qualitative criteria.

Table 1 summarizes the attributes of all the evaluation approaches proposed for the multi-view framework. Some of the approaches presented exist only as theoretical constructs and need to be elaborated further to develop application methods. These include the Generational, Cadastral, Performance-Based and Organizational approaches. The SDI-Readiness, Clearinghouse Suitability and State of play approaches can be applied in the framework in a straightforward manner because the methodologies and application practices already exist. The Programme Evaluation approach still needs to be developed and methods of measurement and assessment need conceptualization. This variety of assessment methods guarantees that a wide range of data on SDIs can be collected. The set of approaches constituting the framework also covers all three classes of evaluation purposes presented by Chelimsky (1997): accountability, knowledge and developmental purposes.
<table>
<thead>
<tr>
<th>Approach</th>
<th>Goal Description</th>
<th>Method</th>
<th>Status</th>
<th>Assessment purpose class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generational</td>
<td>To measure the development of SDIs worldwide</td>
<td>Survey, document study</td>
<td>Not developed</td>
<td>Developmental Knowledge</td>
</tr>
<tr>
<td>Programme Evaluation</td>
<td>To determine the worth and accomplishment of the objectives of SDIs</td>
<td>Case study and survey</td>
<td>Not developed</td>
<td>Developmental Knowledge Accountability</td>
</tr>
<tr>
<td>SDI-Readiness</td>
<td>To assess if the country is ready to embrace the SDI development</td>
<td>Survey</td>
<td>Applicable</td>
<td>Developmental Knowledge</td>
</tr>
<tr>
<td>Cadastral</td>
<td>To measure five evaluation areas of LAS</td>
<td>Survey</td>
<td>Needs improvement</td>
<td>Knowledge Accountability</td>
</tr>
<tr>
<td>Organizational</td>
<td>To measure SDI development from the institutional perspective</td>
<td>Case study</td>
<td>Applicable</td>
<td>Developmental</td>
</tr>
<tr>
<td>Performance-Based</td>
<td>To measure SDI effectiveness, efficiency and reliability</td>
<td>Not available</td>
<td>Needs improvement</td>
<td>Accountability</td>
</tr>
<tr>
<td>Clearinghouse Suitability</td>
<td>To measure the development and impact of SDI clearinghouses worldwide</td>
<td>Survey, key informants</td>
<td>Applicable</td>
<td>Developmental</td>
</tr>
<tr>
<td>State of Play</td>
<td>To measure the status and development of SDIs</td>
<td>Document study, survey, key informants</td>
<td>Applicable</td>
<td>Developmental Accountability</td>
</tr>
<tr>
<td>Pabon's</td>
<td>To measure quality and virtue dimensions of SDI</td>
<td>Case studies, Web survey</td>
<td>Needs improvement</td>
<td>Developmental, Knowledge</td>
</tr>
</tbody>
</table>

The application part of the assessment framework focuses on measuring the indicators for each assessment approach. The selection criteria for the indicators
are the criteria of merit: the descriptors of an evaluand that reflect its capacity to meet needs (Shadish et al., 1991). For example, if interoperability is the criteria of merit of SDI it should be measured with an indicator that best reflects the level of interoperability. The scale of the measure should be defined to allow comparison and ranking of the measured values. The result of the measurement of selected data forms the basis for the assessment of a particular SDI. The best approach and method can be chosen according to the purpose of the evaluation of the SDI (accountability, development or knowledge).

The evaluation part of the framework has two functions: (1) evaluation of the SDI and (2) evaluation of each approach and the whole assessment framework. The first function is the primary one as the main purpose of the research is to assess SDIs. The evaluator makes a judgement on SDI, taking into account the standard of merit determined for each criterion of merit for the particular assessment approach. For example, if interoperability is being measured, each measured value should be placed on a defined scale to make it possible to assess (evaluate) and compare the value of interoperability, either between countries or as a reference to some standard value (benchmarking). A more holistic and bias free picture of specific SDI initiatives can be obtained by interpreting the assessment results for those SDIs from different viewpoints. This will enhance our understanding and assessment of the SDIs.

The second function of the evaluation part is the evaluation of the assessment approaches and the whole framework itself, or meta-evaluation, to ensure that they are acceptable to the stakeholders. Meta-evaluation refers to a variety of activities intended to evaluate the technical quality of evaluations and the conclusions drawn from them. Its purpose is to identify any potential bias that there might be in an evaluation and, using a variety of methods, to estimate their importance (Straw and Cook, 1990). Meta-evaluation can also provide information about the impacts of evaluation activities. Several models of meta-evaluation exist (Cook and Gruder, 1978), but at this early stage in the development of the multi-approach assessment model it is difficult to choose the most suitable one. Nevertheless the meta-evaluation must be performed, especially by the users of the framework, and must follow the application of the multi-approach framework. However, given that the principal feature of the proposed framework is the use of multiple approaches, the same indicators can be used for different assessment approaches and methods. Coming to similar conclusions about the value of one particular SDI using multiple assessment approaches would therefore confirm the validity of the whole assessment framework. This design is in fact a kind of built-in self-evaluation mechanism: the use of multiple, independent approaches and methods used by a number of evaluators guarantees SDI assessment results that accurate reflect reality and have a low bias. The potential overlap between the methods used for different assessment approaches may help to validate the approaches themselves. Moreover, this assessment framework design is related to triangulation research.
methodology which applies and combines several research methodologies in the
study of the same phenomenon. Triangulation is the preferred line of research in
the social sciences because combining multiple observers, theories, methods and
data sources can overcome the intrinsic bias inevitable in single-method, single
observer and single-theory investigation (Denzin, 1990). Evaluation of the
assessment framework and its approaches is crucial for their future usability
because stakeholders will only use its results to improve SDI’s performance if they
accept the framework.

5. DISCUSSION

The core element of this paper is the presentation of the conceptual model of the
SDI assessment framework. The authors intend to apply the assessment
framework in their future research to assess SDIs at the national level (NSDIs).
The multi-view assessment strategy was based on the principles of assessing
Complex Adaptive Systems and general evaluation research. A combination of
multiple approaches and methods generates more complete, more realistic and
less biased assessment results. Multiple assessment methods – case studies,
surveys, key informants and document studies – capture the multifaceted and
complex character of SDI. They guarantee a diversity of SDI data, which in turn
can reflect the complexity of the SDI. The framework is flexible because it permits
evaluation approaches and indicators to be added, removed or corrected – an
especially important feature when the framework is applied iteratively and refined
successively. The relative complexity of the assessment framework presented here
also meets the requirement that truly complex systems should be explored and
understood with complex methods to properly reflect reality. The aim of the
proposed framework is not only to assess SDI performance, but also to deepen our
knowledge about SDI mechanisms and support SDI development.

Some obstacles and difficulties may be encountered when applying the
assessment framework. The issue of timing is the first important consideration,
especially in such a dynamic and constantly evolving environment like SDI. The
simultaneous use of several assessment approaches will generate more realistic
results than if they are conducted sequentially. Therefore the intervals between
data collections for various approaches should be as short as possible to allow
application of the multiple approaches to be synchronized. The next consideration
is the difference in data availability between various assessment approaches and
methods. Because the SDI concept is still very young, some countries may not
produce reports or any other data that could be used in the assessment analysis.
For some assessment approaches and their methods it may be impossible to
collect reliable and complete data, such as reports on SDI finances, expenditure or
revenues figures, and there may be no internal self-assessment reports available.
The last consideration concerns the integration of multiple approaches. The
intended outcome of the integration of all the assessment approaches included in
the framework is to give tangible information on the merits of the SDIs. It is possible, though, that the findings of several assessment approaches will present different pictures of SDI. These differences must be reported so that future investigators can build on such observations (Denzin, 1990).

An important aspect of applying the assessment framework in practice is promoting the use of the evaluation results, and so evaluators must take active steps to increase the use of their results. Shadish et al. (1991) state that evaluators can facilitate the use of evaluations by choosing the right communication channels to disseminate the results and by taking the appropriate stance when dealing with potential users. The appropriate role for the evaluator to adopt is as a servant. The preferred communication channels are writing and presenting evaluation reports, making recommendations for action, publicizing evaluation findings and maintaining close contacts with users to stimulate the use of the results of the assessment.

6. CONCLUSIONS

In this paper we have highlighted four characteristics of SDI that make its assessment specific: its complexity, its many definitions, the often vague objectives and its dynamic nature. To deal with these issues we suggested that the framework should be based on the principles of assessing Complex Adaptive Systems: using multiple assessment strategies, a flexible framework and a multi-perspective view of the assessed object. We argued that the application of the proposed framework would lead to a more complete, realistic and less biased assessment of SDI. We proposed a number of existing and non-existing SDI assessment approaches as building blocks for the framework. We also discussed issues related to the application of the framework in future research. Despite the fact that the multi-approach assessment framework is strongly supported in complexity theory and evaluation practice, and its application results are promising for evaluating SDIs worldwide, we also suggest that the issues of harmonizing the different approaches at one point in time, the difficulties of collecting data for all approaches for all countries and the integration of the results should be examined critically during future application of the assessment framework.

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