Towards a User-centric SDI Framework for Historical and Heritage European Landscape Research *

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Abstract

Spatial scientific research has increasingly become multidisciplinary. The need for different disciplines to share thematic knowledge and information has increased. However, not many Spatial Data Infrastructures (SDIs) have succeeded in facilitating the needs of these multidisciplinary research communities. This article provides a methodological framework for the development of a user-centric SDI and applies it to the academic community that researches the history and heritage of urban and rural landscapes in the Netherlands. In addition, it demonstrates how the users’ objectives and Geospatial Information literacy can be determined, in order to inform the conceptual and technological architecture of a user-centric SDI. The architecture of the historical and heritage landscape SDI focusses on developing a user-centric dashboard, which is placed at the centre of the SDI, and developed as the result of a top-down analysis of the users. The framework and architecture presented function as an example for other third-generation SDIs, and form a reference point for the development of historical and heritage landscape SDIs in Europe.

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1. INTRODUCTION

In the past few decades, spatial research has increasingly become multidisciplinary (Van Manen et al, 2009). The need to share spatial data and exchange information generated by different participants has become an important feature for spatial-oriented disciplines. In this context, the article discusses how a Spatial Data Infrastructure (SDI) can facilitate and stimulate multidisciplinary research. That objective is achieved by focussing on a prominent and growing field of European research and policy dedicated to the understanding and management of historical and heritage landscapes.

This research community is comprised of a heterogeneous body of scholars with varying demands for information and digital functionalities to perform qualitative and quantitative spatial analyses, making it a suitable case to explore user-centric (also known as third-generation) SDI development with. A distinction can be made between user demands in terms of the users’ objectives and their Geospatial Information literacy (GI-literacy), for which we use the definition given by Hennig et al. (2013). They define GI-literacy as the “knowledge, understanding and expertise to be prepared to use spatial data and associated tools in a competent manner and in an emancipatory way” (Hennig et al, 2013, p. 99). The community varies in its GI-literacy, including highly experienced archaeologists, who apply predictive modelling to understand past spatial dynamics, and architects who want to use geospatial information to explore and understand past landscapes, and see how these can be integrated in future plans (Kamermans et al, 2009; Bosma and Kolen, 2010). Besides the high variety of objectives and potentially differing levels of GI-literacy, this community’s needs pose challenges to SDI developers that are also relevant for other SDI initiatives. Researchers who study the history and heritage of the landscape are currently conducting analyses that go beyond administrative national borders; have high demands to valorise research results for a broader public, like citizens; and require relative temporal definition queries on data sets that use different methodologies to define time.

The article contributes to the discussion on how to develop user-centric SDIs. As stated by Hennig and Belgiu (2011), the biggest challenge to come to a truly user-centric SDI is to facilitate the dynamic demands of users. They argue that the way forward is not to let SDI-experts observe the field and design and implement an infrastructure based just on their own technical knowledge and findings, but to involve the end-users throughout the design and implementation
process. We consider this statement to be only partly true. Especially at the initial stage of SDI development an expert-driven (top-down) analysis is required as an essential first building block. Approaching SDI development as an iterative process allows active (bottom-up) user-involvement at a later stage. The article presents a generic approach for achieving a symbiosis between expert-driven and user-involved development. It does so by, firstly, conceptually rethinking SDIs, focussing on the role of the users and distinguishing between GI-literacy and requirements based on users’ objectives. These are emphasised as core drivers for the functionalities that need to be developed in third-generation SDIs. Furthermore, it discusses an iterative development process for third-generation SDIs. Secondly, it presents how this reconceptualised framework is applied to the historical and heritage landscapes research community. It presents the results from an initial top-down analysis of this research community, and presents a roadmap for the symbiosis between top-down and bottom-up development involving users.

2. RETHINKING SDI CONCEPTS

The core function of an SDI is to enable users, beyond the level of a single institute or organisation, to share geospatial information. Since the first research and initiatives to develop SDIs in the early 1990s, researchers have identified three generations of SDIs. SDI initiatives have evolved from first-generation product-based centralised spatial information repositories for small groups of GI-experts to second-generation, top-down information assets management by linking metadata, data, and people; and, third-generation, bottom-up user-centric SDIs (Rajabifard et al, 2002; Rajabifard et al, 2006; Masser, 1998; Hennig and Belgui, 2011; Craglia and Annoni, 2007). This evolution goes parallel with the development of the Internet. The development of faster data transfer technologies and interactive capabilities that the Internet supplies, together with conceptual changes on communication, have influenced the understanding of what an SDI comprises, and how it should be developed.

The constantly evolving character of SDIs has resulted in a continuous redefinition of what an SDI encompasses. It is therefore not surprising that a variety of SDI definitions exist (e.g. Masser, 1998; Chan et al, 2001; Rajabifard et al, 2002; Craglia and Annoni, 2007). The recent study of Hendriks et al. (2012), which presents a thorough analysis of 28 SDI definitions, makes a distinction between SDI objectives and components. SDI objectives are, for instance, the access to, or sharing of, geospatial information, while the components are identified as technologies and human resources.

In redefining SDIs, this article uses the concepts, objectives and components, identified by Hendriks et al. (2012) as a starting point. The users define their objectives which are to be translated into requirements that enable the users to
perform the necessary tasks. However, besides the objectives, the requirements for the SDI are also highly dependent on the users’ GI-literacy. We therefore propose to split the users from the objectives and components, and approach them as separate concepts. Furthermore, we have separated content, and split the remaining components into technological and governance (Figure 1). We treat content as a separate entity because it is determined by the users’ needs, and the other components are developed or implemented according to what the users intend to do with them. In addition to users, content, technological, and governance components, we have extended the concepts of Hendriks et al. (2013) with GI-literacy. As stated in the Introduction, we applied the definition of GI-literacy provided by Hennig who defines it as the “knowledge, understanding and expertise to be prepared to use spatial data and associated tools in a competent manner and in an emancipatory way” (Hennig et al, 2013, p.99). Differences in user GI-literacy result in different SDI implementation requirements. Users with high GI-literacy need different components and education than users with a relatively low level of GI-literacy.

The relationship between GI-literacy, objectives and technological components is of vital importance in the light of user-centric third-generation SDIs. The character of the users’ objectives influences the users’ needs to improve specific GI-skills, thus stimulating the user to increase his or her GI-literacy. However, technological components can be developed that allow users with relatively low GI-literacy to perform tasks that were previously too challenging. Developing a user-centric SDI must therefore focus on the interplay between these concepts. Understanding, and achieving, a balance between the time that users are willing to invest in education and the effort to put in developing technological solutions should be the focus of user-centric SDI development.

**Figure 1 SDI Concepts Redefined**

![Figure 1 SDI Concepts Redefined](image-url)
To apply this reconceptualised SDI concept, the following subsections provide a framework for GI-literacy and an overview of existing technological and governance components. But first, we present a workflow diagram which integrates these concepts, leading to a methodology for the development of a user-centric SDI.

2.1. GI-literacy

Although the relationship of GI-literacy to spatial thinking and education has been previously researched (e.g. Goodchild and Janelle, 2010; Van Leeuwen and Scholten, 2009; Lee and Bednarz, 2012), few have explicitly analysed this topic in relation to SDI development. Hennig et al. (2013) have discussed GI-literacy in the context of spatially-enabled societies, clarifying that GI-literacy has to be seen as the interplay between technological skills and spatial thinking skills. They have provided a clear analysis of the users by looking at skill levels, needs and knowledge, and relating those to the challenges of using SDIs for the support of, what they call, "spatial citizenship". The approach of Hennig et al. is also a valuable starting point for making GI-literacy a workable input for a heterogeneous research community, such as the one discussed here. It makes it possible to evaluate researchers in terms of both their ability to approach their discipline from a spatial angle (formulating relevant spatial questions and adopting spatial concepts), and to deploy geospatial technologies in to solve their research questions. We propose to broaden the GI-literacy concept with different levels, fitting user profiles into a recognisable GI-literacy level. To this end, we propose a model that confronts and combines the study on the conceptions of spatial information and information literacy as developed by Nazzari (2011) with the idea of a GI-skills scale. In essence, Nazzari has developed a contextual model on information literacy for GI in the case of an online distance-learning GIS programme. Her model comprises a framework with five stages that students and academics needs to go through when facing a spatial challenge:

- Perception – the knowledge of the nature and characteristics of GI and being able to view and understand it;
- Preparation – the knowledge of capabilities, applications and limitations of GIS, allowing one to know how to make sense and use of GI and to diagnose knowledge and skill gaps;
- Operation – knowing how to use GIS tools and techniques to make the GI meaningful and usable;
- Communication – knowing ways of presenting and communicating solutions spatially to others;
Maintaining – having knowledge of GI as a dynamic type of data that involves multiple disciplines and various temporal and spatial dimensions for which skills and knowledge need to be constantly updated.

To apply Nazzari’s framework in the developing process of a user-centric SDI, the model is related to the users’ objectives. A certain objective is mapped onto each of the stages defined by Nazzari. For example, if the users’ objective is understanding how the study area looked at a specific moment in history and having access to spatially prepared information generated by other researchers, this objective can be related to perception; if a users’ objective is to model long-term developments of the area by combining various sources necessary to reconstruct past spatial dynamics, the objective is more related to operation and maintaining.

Nazzari’s model can thus be related to the users’ objectives, which reflects the complexity of the spatial questions and the concepts they deploy in their research and hence their spatial thinking skills. However, in order to relate such research to the technological SDI components that need to be developed, we propose to extend the model with the researchers’ technological GI-skills. Because of the fast development of ICT and technological components, the technical skill level of the users can be compensated by these technological components (Van Manen et al, 2009; Goodchild, 2006; Hennig et al, 2013). Therefore, we call for a distinction between GI-literacy related to spatial thinking skills and objectives, for which we apply Nazzari’s framework, and GI-literacy related to technological skills, for which we propose a 4-tiered scale: (1) no GI-knowledge or praxis (e.g. users who understand basic web viewer, but are not familiar with desktop GIS software); (2) basic GIS users (e.g. those familiar with GIS desktop software and basic skills for analysis); (3) advanced GIS users (e.g. those familiar with more complex GIS analysis and understand server technologies); (4) highly advanced GIS users (e.g. those that conduct complex GIS analysis with large data sets who are able to organise their own servers). Technical understanding of how to use the tools is different from understanding how a research discipline can be studied with the help of spatial questions and concepts. The combination of these two aspects is what we refer to as GI-literacy. Approaching GI-literacy from two angles enables us to clearly identify any gaps between spatial thinking skills and technological skills, which can be solved by implementing or developing the technical components (Table 1).
Table 1 Overview on the Effort to be put into Developing Tools for Different Levels of User GI-Literacy

<table>
<thead>
<tr>
<th>Character of SDI objectives</th>
<th>No GI knowledge or Praxis</th>
<th>Basic GIS users</th>
<th>Advanced GIS users</th>
<th>Highly-advanced GIS users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintaining</td>
<td>very high</td>
<td>very high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Communicating</td>
<td>very high</td>
<td>very high</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>Operation</td>
<td>very high</td>
<td>high</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>Preparation</td>
<td>high</td>
<td>medium</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Perception</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

**Technological GI-skills**

**Estimated effort to be put in developing the technological components**

<table>
<thead>
<tr>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
</tr>
</tbody>
</table>

2.2. SDI Components

To apply the GI-literacy framework, the different technological and governance SDI components need to be discussed in detail. Having an overview of the SDI components enables us to apply them to the GI-literacy model discussed above.

2.2.1. **Technological SDI Components**

Through various services, an SDI enables users to share and exchange spatial data and information. The services formulated within the framework of the INSPIRE Directive for a European SDI, as well as by the Open Geospatial Consortium (OGC), offer a clear classification: discovery, view, download, coordinate transformation and processing services (Network Services Drafting Team, 2008; Nebert, 2009; OGC, 2014). In addition to these services, we are adding upload and publishing services.

**Discovery services** enable users to find and discover information. In order to do
so, the data set needs to be enriched with systematically formulated metadata about subject, keywords, data quality, category, the geographical extent, the projected coordinate system, date, etc. (e.g. ISO 19115; ISO, 2014). Through linking online catalogues, users are able to find the spatial information they require.

**Viewing services** enable users to view the geographic information. Protocols for two-dimensional viewing services have been formulated and developed (e.g. Nebert 2009; OGC, 2006), enabling users to access digital spatial information available through a server on a variety of clients. Besides the 2D and 2.5D (elevation models) spatial information, a clear trend towards three- and four- (time) dimensional spatial data is evident (Zlatanova and Beetz, 2012). Three-dimensional viewing services are currently being developed and will become an integral part of SDIs (Basanow et al, 2008; Van Oosterom et al, 2010).

**Download services** enable users to download the information so they can edit or use it for spatial modelling on local machines. Downloading content is useful to deal with issues relating to the performance of viewing services and avoid dependency on a stable Internet, which can for example be problematic during fieldwork.

**Coordinate transformation services** make it possible to combine data sets that are defined in different coordinate systems. Most desktop clients have coordinate transformation tools available. However, coordinate transformation services that enable different projected data to be interchangeable as viewing services will, especially for users with hardly any GI-skills, be very useful.

**Processing services** make it possible for the users to query data sets and execute spatial analysis, such as overlay and proximity, on a server, and generate dynamic outputs (Lucchi and Millot, 2009). Processing services “defines how a client can request the execution of a process, and how the output from the process is handled” (OGC, 2007). It allows users to develop dynamic spatial models based on data sets stored on different servers. Through processing services, Application Programming Interfaces (APIs) can be developed, making it possible to develop custom-made user functionalities. (e.g. City SDK, 2014).

**Upload and publish services** allow users to upload and publish newly produced or edited information. As addressed by Diaz and Schade (2011), SDI initiatives lack mechanisms to assist users to publish content. They propose a service publication profile. Legal issues and complex methods to do so form a bottleneck in most SDI initiatives. Developing easy-to-use, generic publish and upload services will increase the user interaction and better serve the users' needs.
Having discussed the different services as technological components for an SDI, it must be emphasised that these are closely related to standards. Standards in metadata facilitate discovery services; standards in data format are needed for viewing services; standards in projected coordinated systems facilitate data exchange between different projected coordinate systems; standards for the services make SDI initiatives interoperable.

2.2.2. Governance

For whom, and what, spatial information in an SDI is available, and which services are allowed to be used, are also dependent on legal issues, and needs SDI governance. Although the tendency is to put data in the public domain (Kulk and Van Loenen 2012; and e.g., PDOK, 2014), data with restricted access will continue to be generated and require protection. Agreements on data usage are therefore a vital part of SDIs (Box et al, 2010). Data sets on, for example, unique not yet excavated archaeological sites, privacy-sensitive information on architectural features hidden in residences, or costly data that are made available only for research purposes are undesirable in the open domain. From a technological perspective, this means that, to a certain extent, user access has to be controlled through registered accounts.

Another aspect of SDI governance is which party has the responsibility to keep the services updated. Who takes care of server updates and who pays for the services to maintain availability requires ownership and strong leadership (Craglia and Annoni, 2007).

2.3. Components and GI-Literacy User-Centric SDI

In order to correlate GI-literacy to the different SDI components, and generate input for the development of a user-centric SDI, we elaborate Table 1 presented in subsection 2.1 with the different technical SDI components discussed in section 2.2. The result is visualised in Table 2.

As stated above, we propose to divide GI-literacy into users’ technical skills to perform specific tasks and the understanding of which tools are needed for specific objectives. As shown in Table 1, the objectives have been related to the stages formulated by Nazzari, and combined with the technical skill levels of the users, resulting in an overview of the effort necessary to put into the development of GI-tools. By integrating services in Table 1, we obtain the overview in Table 2. The services discussed in subsection 2.2 have been related to the character of the objective. We assume that for all stages of the objectives, discovery, viewing, and coordinate transformation services are needed; operation also needs download; communication requires upload and publish in addition; and maintaining adds processing.
Table 2 Character of the SDI Objective in Relation to the Technical Components

<table>
<thead>
<tr>
<th>Character of SDI objectives</th>
<th>Maintaining</th>
<th>Communicating</th>
<th>Operation</th>
<th>Preparation</th>
<th>Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Processing</td>
<td>Discovery</td>
<td>Processing</td>
<td>Discovery</td>
<td>Discovery</td>
</tr>
<tr>
<td></td>
<td>Upload</td>
<td>Transformation</td>
<td>Processing</td>
<td>Transformation</td>
<td>Viewing</td>
</tr>
<tr>
<td></td>
<td>Upload</td>
<td>Viewing</td>
<td>Upload</td>
<td>Viewing</td>
<td>Viewing</td>
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<tr>
<td></td>
<td>Download</td>
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<td></td>
<td></td>
<td></td>
<td>Download</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Technological GI-skills

**Estimated effort to be put into developing technological components**

- Very high
- High
- Medium
- Low

For users with a low level of GI-skills, more attention needs to be paid in the developing process to the user-friendliness and usability compared with users with a high level of technical skills. Therefore, the more complex the objectives for low-GI-skilled users are, the higher the effort required to develop technological components. If the objective for the user is, for example, the
communication of spatial information to others, but he/she has a low GI-skill level, the effort to develop the necessary download, upload and publish services for these communication objectives are higher than when the GI-skill level of the user is already high.

SDI governance is of vital importance and needs great attention and effort when developing SDIs. However, since these components are conceptually easily implemented – by developing login systems, work with proxy servers, and agreeing who is responsible for the maintenance – these have not been incorporated in the model presented in Table 2.

2.4. Developing Process for User-Centric SDI

The identification of the objectives and the understanding of the GI-literacy of the research community for which the SDI is developed is an iterative process that calls for strong leadership (Craglia and Annoni, 2007). The developing process needs several iterations in which the users’ needs are constantly reviewed. To do so, we propose to apply the “think-play-do” approach, as formulated by Dodgson et al. (2005). The approach states that innovation can be achieved by, first, a phase of thinking about options and creating new ideas, then playing with them to see if they are practical, economical, and marketable, and, finally, doing by implementing the innovation. Steering the development of an SDI is challenging. For example, including at the start many users and actively involving them with respect to their needs at this initial stage of system development endangers the SDI’s success. Users have to see the advantage of putting effort into the development process. From our experience and previous studies, it is evident that not every user is willing to participate from the start, and has to be convinced by clear examples of the added value (De Bree and Rajabifard, 2005; Hennig and Belgui, 2011). In order to obtain an understanding of the users’ demands, we therefore propose first a top-down analysis of the users, and apply the GI-literacy model discussed above in combination with the technological components. Based on the findings of the analysis, prototypes are then developed in close collaboration with a selection of researchers from the academic community. Prototypes act as building blocks for the SDI, and have to function as stimuli to involve other users.

3. A USER-CENTRIC SDI FOR HISTORICAL AND HERITAGE LANDSCAPE RESEARCH

Within disciplines like archaeology, history, historical geography, heritage studies and landscape architecture, three trends can be identified that have fostered the need for a user-centric SDI.
The first trend is the “spatial turn” in the historical and social sciences. Historical developments and heritage issues are increasingly viewed from a spatial perspective, with “landscape” as a prominent analytical concept. The need to reconstruct historical landscapes on a regional or national level by making a synthesis of information produced on a local scale can be seen as one of the major challenges within this framework (Arias and Warf 2009; Boonstra and Schuurman 2010; Van Manen et al. 2009; Wagendonk et al. 2009; Boonstra 2009; Schlögel 2003). The integration of different studies in order to produce a regional synthesis has led to the incorporation of geospatial technologies in these fields of research. The increased interest in geospatial technologies subsequently led to the need for these disciplines to access and share geospatial information.

The second trend is that past-oriented disciplines in landscape research and geospatial research are being increasingly stimulated to valorise their research for spatial planning, urban design, heritage management, and public presentations (Broek and Nijssen, 2009). The disciplines involved transfer their knowledge about historic landscapes to stakeholders and interest groups within society, in order to better co-create programmes for the management, transmission and sustainable development of the cultural and the environmental heritage. The landscape is identified as an important medium for anchoring and storing personal and social memories, and for improving spatial quality and people’s identification with their living environment (Roymans et al, 2009; Van Gorp et al, 2003; Duineveld, 2006).

The third trend is the growing number of disciplines that deal with the history and heritage of the landscape (Van der Valk, 2010; Lazrak et al, 2012; Nijkamp, 2012; Bosma and Kolen, 2010). The history and heritage of our living environment is no longer exclusively studied by past-oriented disciplines like archaeology, art history, historical geography and history, but has become an important source of information and inspiration for present and future-oriented scientists, such as spatial economists, architects, landscape designers, urban planners, and policy makers.

The growing interest from non-historical disciplines and the increased focus of past-oriented disciplines on valorising their research must be seen in light of a shifting heritage paradigm. Whereas the traditional approach to heritage was to solely preserve objects and sites through (legal) protection, the current perspective on heritage is oriented towards incorporating and integrating heritage in spatial, social and economic development. The value and potential of heritage in the present-day and future landscape is widely recognised and has even become an integral part of national and European legislation and policy (Valetta, 1992; Florence, 2000). “Protection through development”, with the aim of sustainably revitalising landscapes for all kinds of social and economic purposes, such as leisure, creative industries and re-wilding, has been introduced in most
European countries as a strategy that is complementary to traditional legal protection (Florence, 2000; Bloemers, 2010; European Commision, 2013; Janssen et al, 2014).

Both European policy and the European scientific community are promoting collaboration between historical and future-oriented disciplines through landscape research funding schemes that require cross-disciplinary partnership, for instance within the framework of Horizon 2020 and the EU Joint Programming Initiative. This confronts the disciplines involved with the challenge of developing new interdisciplinary and trans-disciplinary research methodologies that enable past- and future-oriented landscape researchers and heritage experts to make use of each other's insights by sharing data and information.

3.1. European Landscape Approaches

Dutch universities and other centres of expertise (such as the Dutch Cultural Heritage Agency, RCE) have built up a long-standing tradition in archaeological and historical landscape research, producing results of a high academic standard, thereby achieving a leading position in the international research field (Bloemers, 2010). To analyse the heterogeneous European historical and heritage landscape research, we have therefore used the Dutch landscape research as a point of departure. In studying the Dutch landscape research, we have identified three prominent approaches.

The first comprises fundamental research aimed at reconstructing the characteristics of (parts of) the landscape at a specific moment in time or in particular periods of its development. Recent examples of such period-specific studies are reconstructions of the cultural landscape of the South-Western, Central and South-Eastern parts of the Netherlands during the Roman period (Van Londen, 2006; Jeneson, 2013). Most of these “snapshots” from landscape history, notably in landscape archaeology and historical geography, deal with the relationships and interactions between the natural landscape and human land-use at a particular moment in time or during a relatively short phase of rapid transformation.

The second landscape approach concerns fundamental research aimed at reconstructing the long-term development of (parts of) the landscape. This research focusses on the long-term transformations in landscapes, viewing the landscape at each point in time as a complex interplay between mentalities and values, institutional and governmental changes, social and economic development, and ecological dynamics. Within this diachronic framework, the concept of the “landscape biography” refers to trans-generational and long-term landscape transformations, in which patterns and structures from the past have continuously influenced the spatial ordering and land use of later societies (Kolen,
By analysing the landscape diachronically, researchers aim to identify and reconstruct dynamic and path-dependent processes of change.

The third landscape approach involves the research of present-day heritage landscapes, where the past is currently being preserved, transmitted, remembered, valued, and visualised. This approach includes research on the extent to which heritage is used in planning and policy, how heritage is researched for its economic use and attractiveness, and studies on the socially-contested nature of heritage (Van der Zande and During, 2009). This landscape approach focuses on the recognition and valuation of present-day landscapes as heritage, and which are therefore called "heritagescapes" (Garden, 2006).

3.2. A “Cross-Section” of Dutch Landscape Research

The use of geospatial technologies within the landscape approaches discussed above has greatly increased in recent years (Van Manen et al, 2009; Boonstra and Schuurman, 2010; Wagendonk et al, 2009; Conolly and Lake, 2006; Nijhuis, 2009). To gain insight into the objectives and GI-literacy and what these imply for SDI architecture, a “cross-section” of the Dutch landscape research has been made. For each landscape approach presented above, two representative studies have been selected. By analysing these approaches systematically, we aim to provide the requirements for an SDI of this research community.

3.2.1. Studies on the “Period-Specific Landscape Approach”

The studies selected for the period-specific approach are the recent analysis of the early Neolithic Bandkeramik settlement landscape of Southern Limburg (Amkreutz et al, 2012), and the Roman villa landscape between Tongres and Cologne (Jeneson, 2013). A short description of both studies is provided in Table 3.

Both studies can be characterised as synthesising studies. Both have collected archaeological records for a large geographical area and confronted these with reconstructions of the physical environment, in order to understand and reconstruct the impact of natural landscape features and social and economic changes on past landscape dynamics. The archaeological records collected come from heterogeneous unstructured data sets, and from published and unpublished archaeological reports. To perform spatial analysis, both studies made a thorough, and time-consuming, inventory of the archaeological records based on these sources. The information was extracted from the reports, and digital data sets were harmonised in terms of classifications, extent, resolution, and coordinate system.
Table 3 Period-Specific Landscape Studies

<table>
<thead>
<tr>
<th>PERIOD-SPECIFIC</th>
<th>Title: Exploring the Roman villa world between Tongres and Cologne: a landscape archaeological approach (Jeneson, 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERIOD-SPECIFIC</td>
<td>This study aims to reconstruct the rural world on the loess soils between Tongres and Cologne in the Roman period. The main challenges for the reconstruction of this landscape, dominated by stone-built villas, were the highly dispersed and heterogeneous data sets generated by almost a century of archaeological activities, and how to spatially model uncertainty. Regarding the spatial component of the sites as well as the archaeological information, it was possible to reconstruct two scenarios. It is argued that the use of spatial dimensions is crucial to enable the reappraisal of different types of sites, other than settlements, resulting in a more accurate picture of the original composition and settlement density of these villa landscapes.</td>
</tr>
<tr>
<td>PERIOD-SPECIFIC</td>
<td>Title: Towards an infrastructure for intersite Bandkeramik settlement research (Amkreutz et al, 2012)</td>
</tr>
<tr>
<td>PERIOD-SPECIFIC</td>
<td>To study the relationships in material and economic culture for the Linear Bandkeramik Pottery Culture (5250-4950 BC), there is an ongoing need for a complete analysis of the interaction and interrelationship between settlement and environment. Combining a complete inventory of published and unpublished Bandkeramik sites with a paleo-environmental reconstruction of the landscape, enables researchers to gain insights into reconstructing the habitation of the landscape for this specific period. This research programme generates a digital data set of archaeological activities and past environments that forms the basis for future landscape research.</td>
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A key attribute to the data sets in period-specific analysis involves the definition and proper use of chronological classifications. Especially in the field of archaeology, there are considerable uncertainties in dating. Whereas some sites and features can be dated precisely, most of the features and sites are given a relative dating using constructs such as terminus post quem (date after which) and terminus ante quem (date before which), or by relating sites and features to a period on a rough chronological (often geologically informed) time scale (see Bazelmans et al, 2011). Being able to combine data sets with different temporal definitions is a crucial research tool within the case studies presented. Location of archaeological and paleo-environmental data and the integration of standards on definitions of different time periods are also very important. For example, the Dutch Iron age ends with the arrival of the Romans in 12 BC whereas, for example, the Scandinavian Iron Age last until the 10th century AD.

The environmental data sets used (e.g. paleo-geographical reconstructions, elevation models, and soil maps) come from generic sources such as Alterra (Wageningen University) and TNO Geologische Dienst Nederland (GDN). Furthermore, it is important to observe that both studies go beyond the current...
national borders of the Netherlands. More generally, studying past landscape often goes beyond current administrative borders (McKeague et al, 2012).

**Implications for the SDI**
The users of both regional case studies would benefit considerably from an SDI. Not only can an SDI give them the possibility to find datasets more quickly and easily, but it would also give them the opportunity to store their newly produced research results so that future researchers can contribute to the period-specific reconstructions and analyses more effectively. The biggest challenge for this research community is to structure the enormous data sets. In the Netherlands alone more than 15,000 reports on site-based archaeological research projects have been produced (DANS and RCE, 2014).

The spatial thinking skills and objectives of the researchers discussed above can be characterised as *operation*. In terms of technological skills, researchers need to be able to explore, access, download, and transform the spatial information between different coordinate systems. Since the use of GIS within archaeology is widespread, and GIS has become part of most university archaeological curriculums (Wagendonk et al, 2009; Conolly and Lake, 2006), the technical GIS skill level of the users is that of advanced GIS users. Being able to publish and upload the generated information is needed, but only after completion of the research itself. Content produced by these types of studies is published alongside the conventional publications, such as a research paper, monograph or PhD thesis. Sophisticated publish and upload functionality to regularly upload and publish information and directly share with others is therefore not needed for these studies. Publishing and uploading the newly produced content by contacting SDI specialists would in this case be sufficient. For the development of the SDI, this means that in particular the discovery, viewing, coordinate transformation, and download services are needed. Since the users can be seen as advanced, not much effort needs to be put into developing the interfaces as highly user-friendly.

**3.2.2. Studies on “Landscape Biographies” and Long-Term Developments**
In order to support and facilitate the approach of "Landscape biographies" and the long-term study of landscape change, the research projects of the Drentsche Aa National Landscape (Province of Drenthe) and the Zandstad region (Noord-Brabant) are selected (Spek and Elerie, 2010; Bosma and Kolen, 2010). Instead of a specific period, culture, or historical event, these studies take the layered landscape itself and its integral diachronic dimension as their starting point. Although both are classified as past-oriented approaches, these projects resulted in concepts for better understanding the regional landscape as “heritagescape” and for the sustainable development of this landscape in the future (Zandstad project: Bosma et al, 2006; Drentsche Aa project: BOKD and Kenniscentrum
Landschap, 2010). These projects have produced digital diachronic biographies of the landscape by combining reconstructions and insights from period-specific research and geo-tagging historical sources that were partly made available in other initiatives (e.g. photographs, drawings, documents, etc.).

Table 4 Studies on “Landscape Biographies”and Long-Term Developments

<table>
<thead>
<tr>
<th>LONG-TERM DEVELOPMENT</th>
<th>Title: The Cultural biography of the Drentsche Aa National Landscape (Spek and Elerie, 2010)</th>
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<td>During a five-year research action programme in the Drentsche Aa National Landscape, geologists, archaeologists, historical geographers, toponymists and ecologists put the theoretical concept of the cultural biography of landscape into practice at the regional level. These different disciplinary researchers have used a broad diversity of data sets, including interviews with residents resulting in valuable information about the toponyms. The biography of the Drentsche Aa resulted in an illustrated book and an online digital cultural atlas (BOKD and Kenniscentrum Landschap, 2010), which is being used by spatial planners to develop this landscape, taking the value of remains from the past into account.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>LONG-TERM DEVELOPMENT</th>
<th>Title: The Biography of the Zandstad region (Bosma et al, 2006; Bosma and Kolen, 2010)</th>
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<td></td>
<td>For the area around the Dutch city of Eindhoven (nicknamed “Zandstad”), the Zandstad project generated a digital biography (Bosma et al, 2006). Through this interactive website, users can access information about crucial transformation moments over a time span of 3000 years. The aim of the digital biography is to support planners and designers to make more historically- and heritage-informed decisions in their planning and design tasks.</td>
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</table>

Implications for the SDI

Developing digital biographies is currently being done on an experimental basis. It has the potential to facilitate the dialogue between past- and future-oriented disciplines (Spek and Elerie, 2010; Burgers and Van der Pijl, 2010; De Kleijn et al, 2013). The SDI has to function as a means to this end. By offering generic tools with which regional digital biographies can be developed and information from period-specific landscape studies can be integrated and related, the SDI can play an important role in enriching the planning and policy-making process with historical information and heritage expertise.

An analytical distinction should be made between the researchers who develop digital biographies and the end-users of these biographies, such as landscape designers, urban planners, and landowners. Both the Zandstad and the Drentsche Aa digital biographies are being developed for spatial designers and planners, and therefore have easily operated interfaces. Efforts were made in
organising the information in such a way that users with limited GI-technology skills could have easy access to, and could make use of, the spatial-historical information to understand the historical development, as well as the design potential of the study area.

The objective and spatial thinking skills of the users that prepared the digital biographies can be categorized as communication. The most important technological components for these users are the viewing, discovery, upload and publish services. Since the users of the digital biographies have a low level of GI-literacy, in terms of both spatial thinking and GI-technology skills, effort has to be put into developing usable generic interfaces. This need is reinforced by the strong involvement of the crowd in content acquisition. The biographical approach of the Drentsche Aa has shown a clear example of including volunteers in the data acquisition process. The knowledge from the crowd about the historical toponyms was added as part of the digital biography. Especially in the fields of history and heritage, this trend is very promising. Citizens are willing to digitise historical information (e.g. Woltjer et al, 2014: a system in which archives are transcribed by volunteers). This trend can be classified as Volunteered Geographic Information (Goodchild, 2007).

The research teams that develop these digital biographies can thus be classified as basic to advanced GIS users. The objectives are on the level of communication. They prepare the content available in the digital biographies by connecting, enriching, geo-tagging, and categorising existing data sources, producing new vector and raster data, and presenting the data sets in a communication tool. To improve the digital biography as a research and design concept, these researchers would benefit much from tooling with which they can generate custom-made views of newly produced data on the area or data derived from, for example, period-specific studies.

3.2.3. Studies for the Analysis of “Heritagescapes”

The final category of research projects differs from the biographical category in that their focus is on historical features in the present landscape rather than on historical landscape transformation per se. The study of the economic value of cultural heritage and archaeological predictive modelling in Dutch Policy are selected as studies for this “heritagescape” approach (Lazrak et al, 2014; Van Dommelen and Pen 2013; Kamermans et al, 2009).
Table 5: Studies for the Analysis of "Heritagescapes"

<table>
<thead>
<tr>
<th>HERITAGESCAPES</th>
<th>Title:</th>
<th>The economic value of cultural heritage (Van Duijn and Rouwendal, 2012; Lazrak et al, 2014; Van Loon, 2014)</th>
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<tr>
<td>Title:</td>
<td>HERITAGESCAPES</td>
<td>Archaeological Predictive Modelling in Dutch policy (Kamermans et al, 2009)</td>
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<tr>
<td>Title:</td>
<td></td>
<td>Archaeological predictive modelling in Dutch policy is not to be seen as a single research programme or project, but as a widely performed activity in scientific and commercial research. Through a combination of different analysis techniques, archaeologists have developed predictive models with which they aim to reconstruct where past human activities took place. Besides gaining a better understanding of past dynamics, these predictive models are used in managing archaeological heritage. Although criticised by several academics, the intensity to which areas are researched is increasingly dependent on the outcome of these models.</td>
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The study of the economic value of heritage reveals two important data issues. First, it indicates the importance of detailed and consistent documentation on the data sets. The indicators for cultural heritage used were listed state monuments and protected city- and townscapes, together with number of museum visits (Van Duijn and Rouwendal, 2012; Lazrak et al, 2014; Van Loon 2014). Understanding the quality of these indicators is crucial in interpreting the outcome of models used in spatial economics. The selection criteria of listed buildings and of protected city- and townscapes have changed considerably over time, resulting in a heterogeneous data set (Hellemondt and Van Koningsbruggen, 2010). Using these indicators in a spatial-economic model should therefore be done with caution. Spatial economists are highly dependent on documentation generated by heritage experts.

The second important aspect is that commercial and privacy-sensitive data sets are frequently used (e.g. CBS micro-data sets, NVM data on house prices). Due to legal issues, the possibility to publish these data sets is often limited. Many analyses are therefore presented in an aggregated form (Van Duijn and Rouwendal, 2012).
Another crucial aspect of the research of heritagescapes is the active involvement of public partners. Workshops were organised in which researchers presented their research results to municipalities, using, for example, touchtables to communicate the spatial information between stakeholders. Furthermore, an interactive web viewer is being developed in which the research results are presented interactively (De Kleijn et al, 2012). This interactive web viewer is available for policy makers and the interested public.

In Dutch landscape policy, when spatial interventions take place, archaeological predictive maps are used to decide how intensive the archaeological landscape is to be researched. The quality of the models should be of a high level, and the data therefore need to be well-documented and scientifically profound. However, at present, the models show a large variation in this respect. A coherent standard for archaeological predictive modelling does not yet exist (Verbruggen, 2009), sometimes resulting in unlikely anomalies, especially at the margins of research areas. Furthermore, the model outcomes are currently too much approached as static maps. Therefore, at present, changes in the chances of finding archaeological sites based on new input or changing insights into archaeological predictive modelling have a minimal impact on the existing static maps used in policy.

**Implications for the SDI**

The spatial thinking skills of the spatial economists can be categorized as operational. Their primary objective is to obtain data that can be processed in sophisticated spatial models. The technical GI-skill level is considered to correspond to that of advanced GIS users. Discovery and download services are therefore needed in the SDI. However, the biggest challenge for this interdisciplinary approach is the content. Assessing the usefulness of data sets generated by different disciplines is challenging and highly depends on the data quality described in the metadata of the data sets.

The spatial thinking skills and objectives of the researchers who generate archaeological predictive maps can be classified as maintaining. With constantly updated data sets of the archaeological record, these researchers would highly benefit from SDI processing services. Dynamically integrating data services into complex spatial models generates up-to-date predictive models usable for archaeological heritage policy. At present, predictive modellers would benefit most from download services. However, this research group has a high potential to use processing services as well. Furthermore, they would benefit from functionalities to present their models in viewing services, in the context of policy purposes. The technical GI-skills of the modelling researchers is considered to be highly advanced. The technological components do not, therefore, need to be available through highly user-friendly interfaces.
3.3. Requirements for a European Historical and Heritage Landscape SDI

Based on the cross-section of both the research and research communities that study the history and heritage of landscape, the relevance of an SDI is clear. In all approaches, landscape researchers would benefit considerably from improved availability of data about the history and heritage of the landscape through a structured infrastructure. The researchers vary considerably in their GI-literacy. Furthermore, strong spatial thinking skills are often not matched by in-depth knowledge of geospatial tools. This means that the SDI for this research community should be developed in close cooperation with the users and incorporate a range of content and services. A few characteristics of the landscape research, derived from the studies described above, stand out:

- First, in interdisciplinary research there is an urgent need for high quality metadata, for finding reliable data and information and judging its usefulness.

- Secondly, users will have to be able to download, upload, and publish the data in order to edit or use it in a local GIS and to upload newly produced or edited data.

- Thirdly, user accounts need to be generated in order to deal with legal issues on data usage and privacy-sensitive information.

- Fourthly, a clear trend can be noticed that project-specific interactive web mapping viewers are created as communication tools for sharing knowledge for analytical and valorisation purposes. The biographical approaches in particular will benefit from interactive web viewers, in which VGI capabilities also have a high potential but need to be further researched. The studies presented have put much effort into generating viewers, a trend that is also seen in many other initiatives in the Netherlands.

- Fifthly, these initiatives require connections with digital archives for which information on individual objects is enriched with an exact location. Their incorporation in the viewer is of vital importance.

- And, finally, capabilities to query data sets online are needed to dynamically apply models and (cloud-based) grid computing capabilities to deal with complex models and large data sets.
4. ARCHITECTURE FOR THE SDI FOR THE RESEARCH OF THE HISTORY AND HERITAGE OF THE LANDSCAPE

This section discusses the architecture for an SDI for the research community that studies the history and heritage of the landscape. First, the user functionalities are discussed; second, the technological performance; and, third, the SDI governance.

4.1. The Functional Architecture for the SDI

In order for the variety of users to gain an understanding of, and access to, the SDI, a central URL will have to function as a starting point. However, especially the discovery, viewing and download services should also be accessible through European registries, such as the INSPIRE Geoportal, and national registries, such as the Dutch National Georegistry (European Commission, 2014; NGR, 2014). From there, the users can gain access to, and explanations of, the services the SDI provides. At the core of this website, a user-interface will be implemented that directs users to different services and functionalities. Based on the implications of the landscape approaches for the SDI discussed above, special attention is given to the discovery, viewing and download services. The interfaces in which these services will be accessible require attention from usability design experts, and need to be iteratively designed in consultation with the users. The upload, publish, and processing services need less attention from usability design experts, since these are presumably more used by skilled GI-users.

The analysis presented in the previous section has also identified a need for users to compose their own map views by combining different data sets. To support composed map view creation by users, and enable them to share these with others, user accounts with a login are needed. Accounts will also function to control the access and use of restricted services.

4.2. Technological Performance

In translating user requirements to a working technical infrastructure, we can build on various existing and well-documented services, technologies, and standards resulting from two decades of SDI development (e.g. Nebert 2009; Network Services Drafting Team, 2008; OGC, 2007). An important, and often underestimated, aspect is the performance of the SDI services. Many SDI initiatives suffer from slow-functioning services (e.g. the Geoportal of the Nature SDI takes more than 15 seconds to show: NatureSDI, 2009). A study of Galletta et al. from 2004 already identified a clear relationship between the users’ intention to use a site and the speed of the service. Especially for new visitors, the effect of speed is profound: the longer it takes to call up the information, the less intention they have to use the site again (Galletta et al, 2004).
Therefore, when users have to wait too long to obtain the requested spatial information, or when the interfaces and functionalities are too difficult to grasp, they are not willing to continue using the SDI. The performance of the infrastructure can be optimised by using cloud computing capabilities and tile caching techniques. One of the main advantages of making use of cloud and grid computing services is that the performances are scalable. By monitoring data usage, the server capabilities for specific data sets can be optimised to meet high demand. Peak loads, as a consequence of publicity on the publication of the data sets, can thus be handled by extending the server capabilities to the expected number of hits. All data sets are cached, regardless of how often they are accessed, given that this is the simplest way to improve the speed, and thus the performance. Updates for caches will have to be made regularly with changing data sets. As identified by Loechel and Schmid (2013), there are a large variety of tile caching techniques, which are constantly evolving in order to become faster and robust. To not be dependent on the technical performance of other servers, tile caching capabilities are placed in-between the external server and the user. This enables mapping service caching from other, less well-performing, servers, thus optimising the user experience.

The functionalities to find, view, and generate custom map views have to be high-performing and user-friendly. The functionalities for downloading, uploading, and publishing information need to be stable and well-performing, but user-friendliness is less important since these services are mostly used by technically-skilled, advanced GIS users. Technological developments to improve these functionalities in the user dashboard are one of the key elements that will convince users to actually use the SDI tools that are built.

4.3. SDI Governance

From an SDI governance perspective, the requirements for a successful SDI are twofold. First, a party coordinative institute has to take the on leadership and ensure long-term viability. Second, the users’ requirements have to be closely looked at in order to ensure that their needs are constantly monitored and taken care of. Although the strong coordination and leadership – which is required for implementing an SDI (Craglia and Annoni, 2007) – should not be done primarily in a top-down manner, some institution needs to be made responsible. A suitable institute to fulfil this role for Dutch landscape research would be the University Libraries in close collaboration with the Cultural Heritage Agency (RCE) and data initiatives, such as Digital Archiving and Networked Systems (DANS). Involving partners that have experience and are willing to think about the long term of the infrastructure is vital for any SDI initiative to survive over time. To keep a track of the user involvement, more effort is to be put into “building and maintaining social networks, understanding needs and evaluating social impacts, and delivering results which demonstrably add value to both operational and strategic activities.
of heterogeneous user groups with often conflicting objectives” (Craglia and Annoni, 2007, p.97), in other words, into generating the necessary governance support.

4.4. Implementation Architecture

The architecture as discussed above is currently being implemented (schematically represented in Figure 2). According to the requirements of the landscape research, the VU Geoplaza (UBVU and SPINlab, 2013) is being developed as a research SDI by the Spatial Information laboratory and University Library. Parts of the architecture have already been developed and completed; however, in some cases, fine-tuning is required. Effort is being put into optimising the technical functionality of the viewing services and adding building blocks to the user dashboard. By applying the “think-play-do” approach, as formulated by Dodgson et al. (2005), and developing the SDI cyclically, the development process comprises multiple waves in each of which the developers are provided with the user-requirements and feedback on the infrastructure as it stands. To implement these waves, new projects in this research domain are currently testing the SDI functionality and, in close collaboration with the SDI developers, formulating development needs.

Figure 2 Schematic Representation of SDI Architecture
5. CONCLUSIONS

This article has outlined and made a first step towards the implementation of a methodological framework for the development of a user-centric SDI. The core of the framework is the users’ GI-literacy consisting of the spatial-thinking skills and technical skills necessary for handling geospatial information to perform a specific task. The more complex the task is, the more advanced are the services that need to be incorporated in the SDI. The greater the discrepancy between the users’ spatial thinking skills and their technical knowledge, the more effort is required in the development of these services and/or the users’ training. Furthermore, the framework has emphasised the importance of SDI governance, by addressing leadership and underlining the importance of institutes that are capable of facilitating services in the long term. Additionally, the framework has stressed the importance of the performance of the SDI’s technological services and the need to approach the development process iteratively, in which a top-down (expert-driven) analysis forms the first building block.

The GI-literacy framework has been systematically applied to the research community that studies the history and heritage of the landscape. It has been highlighted how this research community would benefit from an SDI, how a top-down analysis identifies the user’s role and how this can be used as a starting point for a user-centric SDI. An SDI would foster the needs of past- and future-oriented landscape disciplines to find data and information, which, at the moment, is often stored by the individual researchers, research units, institutions and organisations, and is therefore difficult to access. Organising the content and making this findable through discovery services is considered to be fundamental for future research. However, the principal innovations for this research community are: that the architecture presented enables the user to easily generate viewers; that it enables them to implement dynamic services; and that complex models can be run by making use of cloud-based grid computing. These innovations will foster innovative interdisciplinary landscape research by helping to understand and reconstruct past landscape dynamics. Furthermore, they will enable both past- and future-oriented disciplines to exchange information about the landscape and support past-oriented disciplines in valorising their research.

One of the main focuses in the architecture of the user-centric SDI presented is the user-dashboard. The dashboard will be the starting point for most users. The interface of this dashboard has to be clear and user-friendly, an aspect that many SDI initiatives have failed to deliver. Getting the information fast to the users’ client is a vital component of a user-centric SDI. Slow services and broken links discourage users to return.
6. FUTURE DIRECTIONS FOR USER-CENTRIC EUROPEAN LANDSCAPE SDI

The article’s main purpose is to provide a framework for user-centric SDI development, using one transdisciplinary research community – that deals with the history and heritage of the landscape – to illustrate how the framework may be implemented. It does not, therefore, provide empirical results on the added value and impact of the SDI on this research community. Once the framework has been implemented fully, such empirical evaluations can and should indeed take place.

There are three developments that have touched upon and been identified as relevant to this research community, but require further research.

First, there is the potential to analyse written reports and systematically query project databases. Enabling landscape researchers to query the content of project databases and reports systematically would be highly beneficial for this community. In this regard, the current European FP7 project ARIADNE, aimed at developing an infrastructure through which archaeological information is searchable, is promising (ARIADNE, 2012). In some of the work packages of the project data- and text- mining techniques that will result in linked data are applied. The challenge for the SDI for the history and heritage of the landscape is to implement tools developed in projects like ARIADNE and make the data spatially-explicit.

The second opportunity is involving the crowd in generating new information (Goodchild, 2007). Particularly in the fields of history and heritage, citizens are willing to digitise historical information. Volunteered Geographic Information (VGI) has a large potential in SDIs for historical and heritage landscape research, but needs further attention in order to result in generic tools that can be used by landscape researchers as part of the SDI.

The third development for which additional services will need to be developed is to store, view, and process (big and small) 3D spatial data sets. Although not touched upon in this article, the fields of history and heritage have a tendency to produce 3D representations and reconstructions of specific objects or whole landscapes (V-MUST.NET, 2014). Developing the 3D-services with which these data sets can be used stands high on various research agendas (V-MUST.NET, 2014; European Commission, 2013), and they are considered to be a future component of SDI services.

The fourth development is the integration of SDIs into the semantic web and publishing them as linked data. Integrating the semantic web through, for example, Geonames (GeoNames, 2014) not only allows data sources to be spatially
accessible, but also to query the data sets on their relationships through languages and protocols such as SPARQL. The recent development of GeoSPARQL, which allows querying proximity and overlay, thus approaching the capabilities of processing services (OGC, 2011), is highly promising.

ACKNOWLEDGEMENTS

The analysis of the different landscape research approaches and architecture for a user-centric SDI presented in this article has been developed as a result of the NWO funded Integrating Heritage project (file: 380-57-001). The aim of the Integrating Heritage project was to study the needs of an SDI for historical and heritage landscape research. This study resulted in the "Rediscovering Landscape" research programme (Kolen et al, 2011), an interdisciplinary collaboration between the Spatial Information laboratory (SPINlab), the Research institute for the heritage and history of the Cultural Landscape and Urban Environment (CLUE), and the University Library of the VU University Amsterdam. The architecture presented is partly implemented under the flag of the VU Geoplaza project (UBVU and SPINlab, 2013). The authors wish to thank Peter Vos for the technical development and implementation of (parts) of the architecture presented. A second research programme, SDI4URD (Spatial Data Infrastructure for Urban Regions in the Delta), has been executed parallel to the development of the architecture for Rediscovering Landscape. The authors wish to thank project leader Simeon Nedkov and other SPINlab colleagues for their valuable input on the conceptual and technical architecture presented in this article.

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