Chapter 1

General Introduction\(^3\)

1. Introduction

European research into the archaeological, historical and heritage dimensions of landscape is extremely varied. In terms of spatial scale, studies may vary from the national landscape in its international context to the unique landscape settings of local histories or individual buildings. From a temporal perspective, the research field covers changes that took thousands of years (the “longue durée”), as well as thin time slices of only a few years. Studies range from the earliest farming landscapes that emerged during prehistory, to the post-war phenomena of urban sprawl and its endless networks of transport, travel and mobility. Thematically, the focus is on rural as well as urban landscapes, on land and water, on the religious ordering of space as well as economic changes, on designed as well as organically grown landscapes, and as much on spatial values as on spatial physical realities (e.g. Crumley, 2012; Bloemers et al., 2010). Related heritage issues range from strategies of management and preservation to the economic and social values of heritagescapes, and equally challenge academic researchers, conservationists, urban planners, nature developers, landscape designers, and other stakeholders, including “citizen scientists”.

Over the last decade, the varied mosaic of studies, schools and orientations in European landscape research has led to various innovative research strategies. These research strategies emerged out of the shifting paradigm within landscape research in the 1980s towards long-term societal processes and spatial contexts inspired by trends in anthropology and geography. From the 1990s, these approaches were extended with social identities, human agency and other more cognitive aspects. This shifted the view on landscapes from physical entities to mental constructions and the interaction between physical and mental aspects and to human action (Burgers, 2015). Examples of innovative research strategies are Landscape Biography (from now on LB: Kolen, 2005; Kolen et al., 2016) and the recommendation on the Historic Urban Landscape (HUL; UNESCO, 2011).

The landscape biographical approach explores the long-term transformations in landscapes, preferably from prehistory to the present, viewing landscape at each point in time as a reworking of layered environmental legacies and as a complex interplay between the transmission of cultural values and social and economic developments (Kolen, 2005; Roymans et al., 2009). The HUL recommendations emphasise the potential role of heritage as a major resource for urban regeneration and socio-economic development. HUL sees heritage as an asset for sustainable city development and advocates integrating heritage in urban planning and design projects. Furthermore, the recommendations call for the

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\(^3\) This chapter is partly based on the “Rediscovering Landscape” NWO proposal submitted in 2011 and 2015 (NWO file: 380-57-001)
development of new tools and methods, focused on civic engagement, inclusiveness and knowledge exchange (UNESCO, 2011). Apart from LB and HUL, several other innovative research areas have been developed recently that investigate heritage and *longue durée* of landscape developments from economic and ecological perspectives (e.g. Spek, 2004; Crumley, 1994; 2012).

By spanning different eras and spatial dimensions of the landscape, these innovative research strategies face the challenge of having to integrate large amounts of heterogeneous data. Each period has left behind distinct kinds and different combinations of sources. These have been studied by researchers with various disciplinary backgrounds. Moreover, some of the disciplines, like archaeology or historical geography, are further divided into period specialisations producing different terminologies and perspectives as well (Kolen and Renes, 2015). In sum, interdisciplinary landscape researchers are not only faced with large sets of heterogeneous primary sources but also large and varied datasets produced by researchers with different disciplinary backgrounds or period specialisations.

In addition, these innovative landscape strategies face the challenge to exchange knowledge with stakeholders outside academia, such as architects, planners and heritage managers. Strategies aimed at such exchanges are considered transdisciplinary for which we follow the definition provided by Tress, Tress and Van der Valk (2003) who define transdisciplinary projects to integrate both academic researchers from different unrelated disciplines and user-group participants to reach a common goal. Archaeological and historical knowledge often proved to be unappealing to urban planners, landscape designers, policymakers and the public. This is not so much related to the content, but in particular the format in which it is presented (Fairclough and Møller, 2008; Bosma and Kolen, 2010; Janssen et al., 2014). At the same time, heritage is still often seen as limiting the possibilities and the creativity of more future oriented disciplines.

Given the spatiotemporal nature of the research field, this dissertation researches the potential of Geographic Information Science (GIScience) for research into the archaeological, historical and heritage dimensions of landscape. The objective of this research is therefore to bring together the most relevant and recent developments in GIScience with innovative landscape approaches. The research aims to provide insights in future methodological developments and applications of digital GIScience tools for landscape research. We define GIScience in line with Goodchild (2010) who quoted the University Consortium for Geographic Information Science: “*The development and use of theories, methods, technology, and data for understanding geographical processes, relationships and patterns*” (Goodchild, 2010; Mark, 2003). GIScience can thus be characterised as a discipline that interconnects several existing disciplines.

The research presented in this dissertation is part of the rapidly developing field of GIScience. The enormous amount of data that are produced by, for example, sensors to capture the real world, through complex simulations or through geocoding processes from digital tabular and textual datasets is rapidly changing GIScience from a data-scarce to a data-rich environment (Miller and Goodchild, 2015). A trend in this context is also the
growing corpus of open data (Welle Donker et al., 2016). Looking at for instance the Netherlands, previously commercial datasets are now freely accessible (e.g. the Dutch LiDar dataset Actueel Hoogtebestand Nederland (AHN) and the official topographical vector map: see https://www.pdok.nl/en/node and http://www.nationaalgeoregister.nl ).

GIScience is not the only research field confronted with a more data-rich situation. Overall, academic research is currently subject to a digital revolution. The enormous amount of data that increasingly becomes available is often referred to as Big Data. In academic literature, Big Data is frequently characterised by the so called three V’s: Volume, Variety and Velocity. Volume refers to the amount and size of data, variety to the diversity of the data types and velocity to the speed with which data can be generated, analysed, visualised and acted upon (Gandomi and Haider, 2015). On the one hand, the three V’s describe the characteristics of the data, on the other hand they describe the technological tools that are required to analyse and visualise data. We see Big Data as data that pushes to the limits of technological capabilities for analyses and visualisations.

Big Data trends in academic research have led to the emergence of a new discipline: Data Science (e.g. recently the EU funded a project to develop the profession of data science http://edison-project.eu/). This new field of research is currently defining itself and some researchers even predict this will lead to a fourth paradigm in science where academic research is less driven by careful observations, by theory, or simulation, but shifting towards a data-driven approach (Hey et al., 2009). As argued by Goodchild and Miller (2015), this trend is highly interesting for GIScience. However, we should be aware that data-driven research should support and not replace theory and observation-driven research (Miller and Goodchild, 2015).

2. General Aim of the Research

This dissertation researches the opportunities of GIScience for landscape research with a strong focus on possibilities of technologies and methods that produce, process, analyse and visualise Big Data. Although the technological innovations developed in the context of this dissertation are remarkable and cutting edge, its major strength lies in the translation of conceptual approaches in landscape research to the successful applications of technological innovations. To that extent, the dissertation provides an alternative direction to the data-driven approach that is currently noted in the field of Data Science.

In view of the recent developments in GIScience, which are related to Big Data concepts, four opportunities for the innovative landscape approaches have been identified and form the core topics researched in this dissertation:

i. The growing corpus of spatial information generated by the digitalisation of historical sources and archaeological research would highly benefit from a Spatial Data Infrastructure (SDI) approach. A SDI is defined as a coherent system of digital spatial data and information, agreements, standards, technology (hardware and software) and knowledge, providing different users with information needed to carry out their work. SDI research is a prominent topic in GIScience (Craglia, 2006). Stimulated by faster and more interactive internet capabilities, SDIs have evolved
into so called third generation user-centric SDIs (Rajabifard et al., 2002; Rajabifard et al., 2006; Masser, 1998; Hennig and Belgui, 2011; Craglia and Annoni, 2007).

ii. Second, we have observed a trend of landscape researchers working in a more inter- and transdisciplinary way for the purposes of heritage planning. Here we hypothesize a key role for GIScience approaches to translate conceptual innovative landscape methods and tools into digital spatially oriented knowledge interaction tools. By extensively looking at digital geospatial interaction tooling that have been developed for Geodesign purposes (e.g. Eikelboom and Janssen, 2015; Dias et al., 2013; Salter et al., 2009), we believe that the knowledge interactions between the stakeholders can be optimised.

iii. Third, we have identified a high potential to apply 3D geospatial technologies for the analysis of landscapes composed of complex structures. 3D technologies offer new methods to analyse such landscape exchange knowledge on an inter- and transdisciplinary level, yet the application of such technologies in the field of historical, archaeological and heritage landscape research is in an early stage of development and case studies are required where its usefulness and added value can be evaluated.

iv. Fourth, we have witnessed a shift in landscape research towards studying long-term processes on a regional scale. Landscape researchers attempt to apply complex spatial simulation frameworks, which integrate socio-cultural and biological physical factors. Yet, complex models that integrate multiple factors are scarce. As many past aspects and spatial phenomena are uncertain, formulating and modelling extreme scenarios offers a way to generate knowledge on specific hypotheses.

3. Research problems and research questions

As identified above, we hypothesise that, especially considering Big Data developments, GIScience offers a lot of opportunities for the research of the archaeological, historical and heritage dimensions of landscape. The main research question addressed in this dissertation is therefore:

*What significant contributions can recent methods and technologies from GIScience make to innovate the research on the archaeological, historical and heritage dimensions of landscape in light of the digital revolution in academic research?*

In order to answer this research question, we will investigate the advances of applying an SDI approach for this field of research and focus on specific topics which we believe offer significant opportunities. The topics we identified are: GIScience trans- and interdisciplinary tooling, digital 3D technologies for analysing complex multi-layered landscapes and spatial interaction modelling for analysing long-term land use change at the regional scale. In total, we have identified four research problems, for each of which we formulated a research question.
Research problem I & Research Question I (QI):
The first problem considers the data competencies of the various researchers and the current organisation of data sharing. The “digital landscape” of available data on the archaeology and history of the landscape is of a fragmented nature (Guntram, 2014). Data are stored and managed in inaccessible, uncoordinated and dispersed ways by a large number of individual researchers, research units and institutions. Furthermore, the community of landscape researchers is characterised as highly heterogeneous with varying knowledge, understanding and expertise to be able to use spatial data and associated tools in a competent manner and in an emancipatory way. The interchangeability of GIScience tools used in landscape research between various researchers with different disciplinary backgrounds, as well as within disciplines themselves, is hardly discussed and an underestimated problem (Barendse and Bosma, 2010). In addition, methods of supplying and exchanging data and information are insufficiently adapted to the demands of modern landscape research “between” the disciplines and “outside” the academic context to, for example, architects, planners and heritage managers (Bloemers, 2010; Kolen and Renes, 2015; Roymans et al., 2009).

Considering this research problem, we have formulated the following research question:

\[ Q \text{ I: How can a Spatial Data Infrastructure be developed to facilitate the research of the historical, archaeological and heritage dimensions of landscape in order to enhance transdisciplinary and interdisciplinary research, taking into account different disciplinary backgrounds, objectives and IT- and geospatial skills?} \]

The insight that will be derived from answering this question will provide the necessary basis to operationalise the implementation of GIScience tooling for the three topics that follow.

Research problem II & Research Question II (QII):
The second research problem entails the translation of innovative landscape approaches into digital GIScience tooling. As formulated above, heritage assets are often seen as a limiting factor by future oriented disciplines. We assume that this has mostly to do with the format in which the knowledge on the past is presented. Future oriented disciplines, like architecture and spatial planning, experience this as unappealing, making it difficult for them to integrate it in their designs. To address this problem, various innovative conceptual landscape approaches have been developed, like the HUL recommendations and the LB approach. The problem discussed in this dissertation is that so far limited attempts have been made to translate such landscape approaches into digital tooling. Opportunities to support such inter- and transdisciplinary interactions with GIScience tooling are currently unexploited. This leads to the research question:
Q II: How can innovative landscape approaches be translated into digital GIScience interaction tooling for transdisciplinary and interdisciplinary knowledge exchange? How can these be developed and how can these be systematically evaluated?

Research problem III & Research Question III (QIII):
The third research problem considers the analysis and sharing of knowledge of highly complex urban and rural landscapes on a local scale. For example, in the “eternal” city of Rome, every period has been built upon the remains from earlier periods, resulting in multiple vertical temporal layers where different elements have been built upon, destroyed, rebuilt or deliberately removed to uncover previous periods (Renes, 2016; Burgers, 2015). For landscapes that are composed of complex structures, it is difficult to share and integrate knowledge on the horizontal and vertical layers derived from different research activities.

Over the last decade, the use of 3D technologies in digital earth applications has grown considerably. For the analysis of complex archaeological sites, the use of 3D technologies for sharing knowledge on complex and layered landscapes and to perform spatial analysis was in 2009 still believed to be too costly and too complex to deal with (Wagtendonk et al., 2009). However, recently the methods and sensors to obtain a virtual digital equivalent of a complex landscape have evolved considerably. The tools needed are not as costly as they used to be. Moreover, the availability of more user-friendly 3D software has increased and 3D software components have been developed as Free and Open Source Software (FOSS). However, despite various efforts (e.g. Basanow et al., 2008; Krüger and Meinel, 2008; Stoter et al., 2011; Zhang et al., 2014; Hu et al., 2015; Hunter et al., 2015; Von Schwerin, 2016), the tooling that allows sharing and analysing complex sites are not yet standardised or easy to implement. The main challenge is how to collect, integrate, share and analyse data of complex multi-layered urban and rural landscapes. On the one hand, this involves Big Data challenges, since the visualisation and analysis of detailed 3D spatial data are pushing the limits of available technological capabilities (Van Oosterom et al., 2010). On the other hand, the technologies must be applied keeping in mind what landscape research problems it aims to tackle. This leads to the following research question:

Q III: How can a useful 3D application be developed allowing landscape researchers to share and analyse complex and layered historical, archaeological and heritage landscapes?

Research problem IV & Research Question IV (QIV):
The fourth problem ponders the understanding of long-term processes. In order to study long-term processes of interactions between humans and their environment, landscape researchers – especially from the landscape archaeological domain – increasingly apply simulation models (Lake, 2014). The simulation models are used to analyse past spatial dynamics, to test hypotheses on past processes and for predictive modelling purposes to estimate incomplete archaeological records.
A major challenge for applying such simulation models is to integrate complex sociological and cultural aspects (Lake, 2014). Since most of the simulation modelling in landscape archaeology has been derived from evolutionary archaeology and the study of the early stages of human evolution, rather than more complex approaches developed for simulating modern societies, the integration of more complex sociological and cultural aspects remains rather behind. Another major problem for applying simulation models is to deal with gaps in the data. Especially archaeological and historical reconstructions of land use suffer from a lack of information on for example demography, physical conditions of the landscape and interregional trade. The research question we have therefore formulated for this topic is:

Q IV: How can long-term spatial developments be analysed using simulation methods and models that integrate cultural and natural factors through multiple scenarios?

4. Methodological Framework

In order to answer the research questions, this dissertation applies an empirical case study approach. The main researcher, and author of this dissertation, has participated as the GIScience engineer and researcher in several landscape research case studies. In each case, a qualitative analysis on the geographical information needs of the researchers who study the historical, archaeological and heritage dimensions of the landscape has been performed. The results of these user requirement analyses are translated into conceptual frameworks on how specific landscape research problems can be approached using geospatial technologies to their full potential. This is done in the context of the three topics identified above, focussing on advances of an SDI approach in light of the recent digital revolution. The development, implementation and evaluation of the GIScience tooling for landscape research in this dissertation produce an empirical study. As a common point of departure, the remainder of the section will outline the GIScience framework and the definition of landscape research that are applied throughout the dissertation.

4.1. Framework for GIScience

As stated above, the field of GIScience can be defined as “the development and use of theories, methods, technology, and data for understanding geographical processes, relationships and patterns” (Goodchild, 2010; Mark, 2003). GIScience is often associated with the term Geographic Information Systems (GIS). The distinction between the two is, however, not always very clear. Exemplary for this is the name of the *International Journal of Geographical Information Science* which before 1997 used to be *the International Journal of Geographical Information Systems*. In an editorial of this journal published in 2017, the term GIS is even used interchangeably as GISystem and GIScience (Yuan, 2017). In this dissertation, we follow the distinction made by Fotheringham and Wilson (2007) and Longley et al. (2005) who define GIS as an object or tool to store, analyse and explore
geospatial information, whereas GIScience is considered to be a much broader framework of technologies, methods and knowledge to research and understand spatial phenomena. Researchers have produced various lists describing the components of GIScience. The multitude of such lists has led us to summarise the two influential perspectives of Goodchild (1992; 2010) and of Fotheringham and Wilson (2007). Based on the components they identify we propose a reduced framework existing of four core components: organisational, data, analytical, and visualisation and communication (figure 1).

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Data collection and measurement</td>
<td>capture</td>
<td>Data</td>
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<tr>
<td>Data capture; Spatial Statistics</td>
<td>retrieval</td>
<td></td>
</tr>
<tr>
<td>Institutional managerial and ethical issues</td>
<td>management</td>
<td>Organisational</td>
</tr>
<tr>
<td>Data structures, algorithms and processes</td>
<td>integration</td>
<td></td>
</tr>
<tr>
<td>Analytical tools</td>
<td>storage</td>
<td>Analytical</td>
</tr>
<tr>
<td>Data modelling and theories of spatial data</td>
<td>modelling</td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>display</td>
<td>Visualisation and communication</td>
</tr>
</tbody>
</table>

Figure 1. GIScience Components

[1] In 2009, Scholten and colleagues explored the status of geographic technology adoption in science, based on their research they have developed a first version of the framework for geospatial technologies in science which they use in various educational programs (e.g. the UNIGIS MSc Programme www.unigis.nl, the national GI-minor http://www.nationalegiminor.nl/), but never published otherwise.

a. Organisational

The first component we identified is the organisational. This component consists of the governance for the use of geospatial technologies, data and standards. The component includes agreements on who can work with the data, according to which data format these are structured and standards on how elements are defined. Furthermore, this component represents standards in how analytical and simulation spatial models are structured so they can be reused by others. To achieve this, tremendous efforts have been made by for instance the Open Geospatial Consortium (OGC, http://www.opengeospatial.org/) and in the context of the EU INSPIRE Directive (http://inspire.ec.europa.eu/).

b. Data

The second component is the data. This component exists of the actual data that can be integrated and analysed. Parts of this component are methods for data capturing, data storage, and retrieval. The data in this framework includes dynamic and static data.

c. Analytical

The third component we distinguish is the spatial analytical framework. From an academic perspective, this framework is considered to be the most prominent as it contains spatial
theory and enables researchers to analyse spatial patterns in order to generate a better understanding of spatial phenomena, spatial correlations and processes.

d. **Visualisation and communication**

The fourth component is composed of the visualisation and communication. This component is essential for communicating, sharing and exchanging knowledge derived from geospatial analysis and technologies as geospatial information. This can either be in a static map or through interactive 2, 3 and 4 (time) dimensional digital mapping instruments.

These four components form the core for the GIScience framework proposed and applied in this dissertation (figure 2).

The various components are strongly interwined. The use of geospatial technologies cuts right through the different components and are composed of elements from all components. We define geospatial technologies as the range of instruments for digitally collecting, manipulating, communicating, sharing, visualising and analysing spatiotemporal information, together with instruments to simulate spatiotemporal phenomena. Our understanding of geospatial technologies is strongly related to the definitions of Geographic Information Systems (GIS) provided by various scholars (Burrough, 1998; Longley et al., 2005; Worboys et al., 2004). However, we deliberately make a distinction between GIS and geospatial technologies, since GIS are often solely associated with a
software package. To avoid the common misconception that GIS equates a software package we use geospatial technologies instead.

The different disciplines also cut through all the components, because the questions posed by the disciplines and the skills of the users determine how the geospatial technology should be organised and put to use. In the framework, the field of SDI is more related to the organisational and data components. The academic disciplinary challenges that entail spatial thinking and the spatial turn in landscape research (see 1.3.2) are more related to the analytical and visualisation components.

4.2. Landscape research

We follow the definition of landscape of the European Landscape Convention (Florence, 2000):

“ ‘Landscape’ means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors.”

This definition covers the whole spectrum of rural and urban landscapes, including archaeological relics and historical buildings, in interaction with the various and dynamic ways in which people use those landscapes. Moreover, this definition includes the physical properties of landscapes as well as the cultural specific perceptions of landscape in the past and present.

4.2.1. Landscape history and archaeological research

The so-called “spatial turn” in the historical and social sciences (Schlögel, 2003; Warf and Arias, 2008; Goodchild and Janelle, 2010) has motivated scholars in the humanities to view historical topics from a spatial and environmental perspective, frequently using “landscape” as a key concept. Within the field of archaeology, the focus on landscape was already introduced earlier. Inspired by trends in anthropology and geography (i.e. New Geography and Braudel’s Annales School, see Burgers, 2015; Kluiving and Guttmann-Bond, 2012), the focus shifted to landscapes, long-term societal processes and spatial contexts. Researchers placed archaeological time frames in broader spatial and temporal contexts. From the 1990s, these approaches were extended by concentrating on social identities, human agency and more cognitive aspects, which shifted the view on landscapes from physical entities to mental constructions (Burgers, 2015; Moreland, 1992; Ashmore et al., 1999; Cifani and Stoddart, 2012). Together these trends in historical and archaeological research have put fundamental research of the history of landscapes on the scientific research agenda.

4.2.2. Heritagescapes

The analysis of heritagescapes stands for sections in the present-day landscape where the past is being preserved, transmitted, remembered and/or visualised in active and conscious
ways. Heritagescapes are mostly located where important events took place in the past, but they may also develop where people prefer to visualise those events (and transmit the memory thereof) for social, political and economic reasons. Innovative contributions to the study of heritagescapes are the focus on their economic value and attractiveness (Van Duijn and Rouwendal, 2013), their spatial planning context (Janssen et al., 2014; Lusiani and Zan, 2013) and their socially contested nature (e.g. Van der Laarse, 2016). The interest in heritagescapes has grown significantly and has resulted in new research approaches. Architects, urban planners and landscape designers are now invited to collaborate closely with experts in the field of archaeology, landscape history and architectural history. This requires innovative formats for transdisciplinary research to stimulate inclusiveness, with academics from various fields collaborating closely with non-academics in order to develop new knowledge and achieve common goals in the field of spatial design and environmental sustainability (Van der Valk, 2010; Janssen et al., 2014; Lusiani and Zan, 2013).

5. Dissertation structure
This dissertation provides an in-depth analysis on the opportunities of GIScience and the possibilities of a data-rich environment for the research community that focusses on the historical, archaeological and heritage dimensions of landscape. It does so by presenting four main chapters which are either published or expected to be published as research articles in peer-reviewed journals (table 1). The different chapters aim to provide insights that help answer the research questions (table 2).

The dissertation starts with a qualitative analysis on how a SDI that facilitates the research of the historical, archaeological and heritage dimensions of landscape can be developed (Chapter 2). This chapter aims to provide an answer to the first research question (Q.I) and provides a starting point for the following chapters.

In the third chapter, the challenge of trans- and interdisciplinary knowledge exchange of urban historical and heritage landscapes is adressed. It aims to extend the heritage management arrangement tools recommended through HUL with digital methods and digital tooling from the GIScience domain. It presents the design, deployment and evaluation of a heritage instrument, the “digital cultural biography” (DCB), to allow future oriented disciplines to make more historical and heritage informed decisions. This chapter aims to make three contributions. First, it presents a methodology to collect and disseminate geographic information across disciplines by applying the biography of the landscape research strategy. Second, it presents how to translate such a landscape approach into a digital heritage instrument using the most recent geospatial technologies. Third, it presents the applicability of this instrument by evaluating the added value in the course of a design experiment. The chapter aims to provide an answer to research question Q.II.
**Table 1. Publication details of chapters**

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Introduction: Innovating Landscape Research through Geographic Information Science</th>
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| Chapter 2 | Towards a User-centric SDI Framework for Historical and Heritage European Landscape Research  
| Chapter 3 | The Digital Cultural Biography, a Digital Tool for Interdisciplinary Knowledge Exchange on the History and Heritage of the Urban Landscape.  
| Chapter 4 | 3D geospatial technology research tools for analysing complex sites.  
| Chapter 5 | Simulating past land use patterns: integrating natural and cultural factors.  
            De Kleijn, M., Beijaard, F., Koomen, E., Van Lanen, R.J. (in prep). Simulating past land use patterns; the impact of the Romans on the Lower-Rhine delta in the first century AD. (submitted)  
| Chapter 6 | Conclusions |

In the fourth chapter a case study is presented for the development of a 3D geospatial application for the complex multi-layered archaeological landscape of the Via Appia Antica near Rome. The Via Appia is known as the queen of roads, running from Rome to Brindisi in the south of Italy. The road was constructed from 312 BCE onwards, and has seen many changes since. In antiquity, the Via Appia was an area flourishing with various cultural, economic, and religious activities, which have left its physical traces in the current landscape. Traces and ruins of funerary monuments, villas, sanctuaries and farmsteads are still visible in the landscape around the road. In medieval times, the areas around Rome fell into decay. The ancient structures, especially marble and travertine slabs were reused as building material or fell victim to treasure hunters. In the early 1800s, it was decided to protect the landscape of the Via Appia near Rome. In the following period, landscape architects and artists were commissioned to rearrange the area, resulting in a romantic
landscape with reconstructions of sometimes doubtful quality and with ancient bricks, reliefs and statues put as museum pieces alongside the road. Trees have been added creating a pleasant area to walk or have a picnic, something which in present days local Italians do frequently on Sundays.

**Table 2. Overview of which research questions are treated in which chapter**

<table>
<thead>
<tr>
<th>Research question</th>
<th>Chapter(s)</th>
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<tbody>
<tr>
<td>What significant contributions can recent methods and technologies from GIScience make to innovate the research on the archaeological, historical and heritage dimensions of landscape in light of the digital revolution in academic research?</td>
<td>All</td>
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<tr>
<td>Q I: How can a Spatial Data Infrastructure be developed to facilitate the research of the historical, archaeological and heritage dimensions of landscape in order to enhance transdisciplinary and interdisciplinary research, taking into account different disciplinary backgrounds, objectives and IT- and geospatial skills?</td>
<td>Chapter 2</td>
</tr>
<tr>
<td>Q II: How can innovative landscape approaches be translated into digital GIScience interaction tooling for transdisciplinary and interdisciplinary knowledge exchange? How can these be developed and how can these be systematically evaluated?</td>
<td>Chapters 2,3,4</td>
</tr>
<tr>
<td>Q III: How can a useful 3D application be developed allowing landscape researchers to share and analyse complex and layered historical, archaeological and heritage landscapes?</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>Q IV: How can long-term spatial developments be analysed using simulation methods and models that integrate cultural and natural factors through multiple scenarios?</td>
<td>Chapter 5</td>
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The changes of the Via Appia over time resulted in multiple vertical layers where through time, elements have been built upon, destroyed, rebuilt or removed to uncover previous periods. This highly complex and multi-layered nature provides a perfect laboratory to research how 3D technologies can handle large datasets and facilitate archaeology and heritage research to analyse complex landscapes. This chapter exists of two parts: first, it presents the development of a 3D digital geospatial tool from the perspective of the archaeological domain; second, it provides a more technologically in-depth approach for the GIScience research community that studies ways to virtually represent the earth. This chapter aims to answer research questions Q III and Q II.

The fifth chapter introduces a simulation framework to study long-term land-use change. The aim of this chapter is to research how this simulation framework can integrate cultural and natural factors in order to understand long-term spatial developments. The basic principle of the framework is that it simulates land-use patterns based on estimated regional demands for various types of use and local assessments of suitable locations for these uses. To balance the demand for land for different types of use with the supply of suitable locations a logit-type approach is applied that simulates the competition for land.

Chapter 5 exists of two articles. The first article introduces the modelling framework and applies it to the western part of the Lower Rhine region during the early- and middle-Roman periods. It evaluates hypotheses posed by other researchers on the demand for
woodland and food producing land use types by working with a range of scenarios. The second article elaborates on the model by extending the time range to the early medieval period and focusses on the eastern part of the Dutch Rhine-Meuse delta. In addition, a demographic model is introduced producing different scenario configurations on the demand for land for different purposes. Together, both articles aim to produce insights that answer research question Q IV.

The dissertation concludes with a summary of the main findings and an answer to the research questions formulated above. Finally, it provides an overview of the main lessons learned and reflects on future directions for landscape research from a GIScience and Data Science perspective.
References


