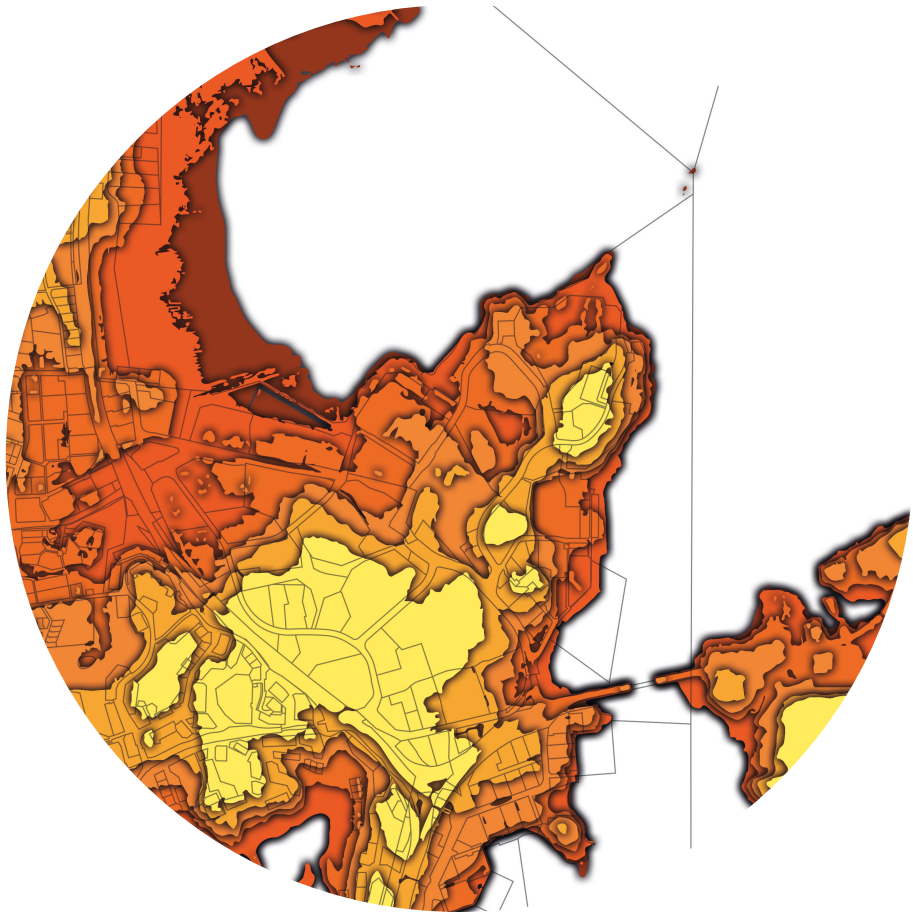
Department of Built Environment

Towards a future cadastral system: An exploration of the Finnish case

Pauliina Krigsholm



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Towards a future cadastral system: An exploration of the Finnish case

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Abstract

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Abstract

Cadastral system as the 'where' component of a property rights system is central to effective land markets, land use and sustainable development. The foundation of any cadastral system, the relationship between people and land, is constantly altering and cadastral systems as well have evolved over time in response to these changes. The focus of this dissertation is on understanding the cadastral system dynamism, and more specifically, the potential future changes of cadastral systems. Empirically the main focus is on the Finnish cadastral system that presents an example of a mature cadastral system with long traditions on registration of land related interests.

This dissertation suggests that the future of cadastral systems should be approached from a holistic and systemic perspective and, therefore, integrates concepts and knowledge from the disciplines of futures studies and socio-technical transition studies. The dissertation adopts a mixed method approach with a greater emphasis on qualitative research methods. Literary sources, a Delphi questionnaire, interviews, and focus group meetings are used in data collection.

This dissertation provides a refined and revised understanding of what drives change in the context of land administration and how the mature cadastral systems might develop in the future. Exploration of emerging issues of change reveals the increasing awareness of the multi-purpose role of cadastral systems, as the identified issues range from technology-oriented ones to political, economic, environmental, and social issues. Overall, the findings suggest that the future of cadastral systems is a complex issue that cannot be reduced to individual technologies or innovations. Rather, this dissertation argues that more emphasis should be put on the institutional foundations, i.e., on the elements that coordinate and stabilise the established systems when the goal is to detect distinctively alternative configurations for cadastral systems.

The academic value of this thesis is in bridging the gap between land administration literature and futures studies and socio-technical transition studies, and in creating comprehensive understanding of cadastral system dynamism. The base of evidence obtained in this research also provides new and fresh insights to actors of land administration domain.

Keywords land administration; cadastral systems; cadastre; land registration; future; signals; trends; pathways; user group perspective

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Tiivistelmä

Katasterijärjestelmä listaa kiinteistöjen sijainnit ja niihin liittyvät oikeudet, ja tukee täten muun muassa maa- ja kiinteistömarkkinoiden toimintaa sekä kestävää maankäyttöä. Jokaisen katasterijärjestelmän pohjana on ihmisen ja maan välinen suhde, jonka dynaamisesta luonteesta johtuen myös katasterijärjestelmät ovat kehittyneet kautta aikojen. Tämä väitöskirja pyrkii lisäämään ymmärrystä katasterijärjestelmien dynamiikasta ja erityisesti siitä, kuinka järjestelmät mahdollisesti kehittyvät tulevaisuudessa. Tutkimus keskittyy Suomen katasterijärjestelmän tapaukseen, joka tarjoaa esimerkin kehittyneestä kiinteistöjärjestelmästä, jossa kiinteistöihin liittyvien oikeuksien kirjaamiseen liittyy pitkä traditio.

Tässä väitöskirjassa ehdotetaan, että katasterijärjestelmien tulevaisuutta tulisi lähestyä kokonaisvaltaisesti ja systeemilähtöisesti, minkä vuoksi tiedon ja konseptien integroiminen tulevaisuudentutkimuksen sekä sosioteknisten järjestelmien tutkimuksen aloilta on työssä keskeisessä osassa. Tutkimuksessa hyödynnetään monimenetelmällistä lähestymistapaa, jonka painopiste on laadullisissa tutkimusmenetelmissä. Tutkimuksen aineisto on koottu kirjallisista lähteistä, Delphi-kyselystä, haastatteluista sekä fokusryhmä-tapaamisista.

Tämä väitöskirja lisää ymmärrystä katasterijärjestelmien muutosta ajavista tekijöistä sekä mahdollisista muutospoluista. Tunnistetut muutosvoimat edustavat monipuolisesti niin teknologisia, poliittisia, taloudellisia, ympäristöllisiä kuin sosiaalisia muutoksia, mikä vahvistaa näkemystä siitä, että katasterijärjestelmä hahmotetaan yhä kasvavassa määrin monitoimintoisena järjestelmänä. Kokonaisuudessaan tämän väitöskirjan tulokset antavat ymmärtää, että katasterijärjestelmien tulevaisuus on monisyinen kysymys, jota ei kannata lähestyä yksittäisten teknologioiden tai innovaatioiden kautta. Sen sijaan tässä työssä ehdotetaan, että huomio kannattaa suunnata katasterijärjestelmän institutionaaliseen perustaan eli järjestelmää koordinoiviin ja tasapainottaviin elementteihin, mikäli tavoitteena on rakentaa nykytilasta selvästi poikkeavia tulevaisuudenkuvauksia katasterijärjestelmälle.

Väitöskirjan akateeminen merkitys muodostuu sen poikkitieteellisestä lähestymistavasta sekä kokonaisvaltaisen ymmärryksen luomisesta katasterijärjestelmien dynaamisuuteen liittyen. Tutkimuksen empiiriset havainnot tarjoaat lisäksi uudenlaisia näkemyksiä maanmittausalan ja laajemmin maanhallinnan alan toimijoille ja organisaatioille.

Avainsanat Maanhallinta; kiinteistöjärjestelmä; katasterijärjestelmä; kiinteistörekisteri; lainhuuto- ja kiinnitysrekisteri; tulevaisuus; trendit; muutospolut; käyttäjäryhmänäkökulma

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Soon after the beginning of my doctoral studies I remember someone saying that accomplishing a doctoral degree is a (mental) process. I also remember that my initial reaction to that comment was to laugh quietly inside. Well, fast-forward few years and that is exactly how I'd describe this all. And now the time has come to acknowledge all those people that have been part of my process.

To begin, thanks to the pre-examiners, Prof. Jenny Paulsson and Prof. Jaap Zevenbergen for dedicating time to read my work and to give some insightful comments that gave the final polish to this dissertation. Additional thanks to Prof. Zevenbergen for agreeing to act as my opponent.

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Since the beginning of my doctoral studies we have formed a strong team with my supervisor slash thesis advisor, Prof. Kirsikka Riekkinen. I can sincerely say there is no one else I'd have rather teamed up with. During these years you have shown that perseverance and patience lead to great things, and that continues to inspire me every day. After countless laughs and many hours spent together at the office and outside it, too, we have grown to be friends as well. And for that I am very grateful for. So, thanks Kirsikka for advising and supporting me through this process.

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Helsinki, March 2020

Pauliina

Contents

List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their numerals

1. Krigsholm, Pauliina; Riekkinen, Kirsikka. 2019. Applying Text Mining for Identifying Future Signals of Land Administration. Land, 8(12), https://doi.org/10.3390/land8120181

2. Krigsholm, Pauliina; Zavialova, Sofia; Riekkinen, Kirsikka; Ståhle, Pirjo; Viitanen, Kauko. 2017. Understanding the future of the Finnish cadastral system: A Delphi study. Land Use Policy, 68, 133—140, http://dx.doi.org/10.1016/j.landusepol.2017.07.032

3. Krigsholm, Pauliina; Riekkinen, Kirsikka; Ståhle, Pirjo. 2018. The Changing Uses of Cadastral Information: A User-Driven Case Study. Land, 7, 83, https://doi.org/10.3390/land7030083

4. Krigsholm, Pauliina; Riekkinen, Kirsikka; Ståhle, Pirjo. 2020. Pathways for a future cadastral system: A socio-technical approach. Land Use Policy, 94, https://doi.org/10.1016/j.landusepol.2020.104504

Author's Contribution

Paper I: Applying Text Mining for Identifying Future Signals of Land Administration

The author was solely responsible for the methodology, the analysis and the visualisation of the article. The author and Kirsikka Riekkinen were jointly responsible for initiating the study and writing the article.

Paper II: Understanding the Future of the Finnish Cadastral System: A Delphi Study

The author, Sofia Zavialova and Kirsikka Riekkinen designed and conducted the Delphi survey. The author was solely responsible for the analysis and for writing the article. Kirsikka Riekkinen, Pirjo Ståhle and Kauko Viitanen contributed to developing the article's idea together with the author and provided comments on the manuscript.

Paper III: The Changing Uses of Cadastral Information: A User-Driven Case Study

The author was solely responsible for conducting the interviews, the analysis and writing the article. Kirsikka Riekkinen and Pirjo Ståhle contributed to developing the article's idea together with the author and provided comments on the manuscript.

Paper IV: Pathways for a Future Cadastral System: A Socio-Technical Approach

The author was solely responsible for the analysis and for writing the article. Together with the author, Kirsikka Riekkinen and Pirjo Ståhle contributed to the organisation of the focus group meetings and the development of the article's idea as well as providing comments on the manuscript.

1. Introduction

1.1 Background and motivation

A strong consensus prevails about the importance of well-defined land and property interests (De Soto, 2000; Feder and Nishio, 1999). With fewer disputes about who owns land and is allowed to use it, for example, land can be used in a more efficient and sustainable manner.[1] Cadastral systems, which are designed for recording the physical location of real properties and listing real property rights, play a central role in delivering this security. In the academic literature, cadastral systems have been approached mainly from a technical or juridical perspective. More technically oriented studies have offered insights on the optimal ways of registering land and property interests (e.g., Kalantari et al., 2008; Stoter et al., 2017). Legal studies, on the other hand, have contributed, for example, to the development of the 3D property concept and terminology across jurisdictions (e.g., Paulsson and Paasch, 2013).

The dynamic relationship between people and land has driven and is expected to continue to drive the reform of cadastral systems (Ting and Williamson, 1999). Commonly, four development phases, from fiscal and juridical cadastre to planning and multipurpose systems, are recognised for cadastral systems (Williamson et al., 2010). The land administration sector and cadastral and mapping agencies have shown broad interest in understanding how this development will continue in future. This interest has been manifested, for instance, in the well-known publications *Cadastre 2014* (Kaufmann and Steudler, 1998) and *Cadastre 2014 and Beyond* (Williamson et al., 2014) initiated by the International Federation of Surveyors (FIG). Drawing on global developments, *Cadastre 2014* provided a set of six guiding statements for a future cadastral system that moves from a map-centric to a data-centric view. *Cadastre 2014 and Beyond* subsequently reviewed the status of these statements and added new perspectives to the debate about the future role of cadastral systems. National level organisations, as well, have put substantial effort into envisioning their own future s (e.g., ICSM 2014; LINZ 2014). These publications anticipated that a gap would emerge between what the current reconfigurations of cadastral systems can serve and what the needs of society will be in the future. Hence, their

[1] Globally speaking, approximately mere 30 percent of land rights are documented (Enemark et al., 2014). The main focus of this dissertation is on a country where recording of land rights has a long history and the coverage and reliability of registers of cadastral system is high. Therefore, the challenges of delivering land right documentation are not covered here.

primary goal was to provide guidance on how the evolution of a country's cadastral system should be organised to prevent this gap's growing too wide.

Despite the active debate on the role and purpose of future cadastral systems, the existing evidence base on cadastral trends is narrow and dates back to the turn of the millennium (Ting and Williamson, 1999). Since then, technological development has been rapid, urbanisation has continued to accelerate and, overall, we are living in an increasingly complex and connected world. More recently, Riekkinen et al. (2016) have adopted a forward-looking perspective and studied the future themes of the Finnish cadastral system. They focus, however, primarilly on providing an overview of the phenomena intersecting with the operational environment of the Finnish cadastral system and grouping those phenomena under coherent themes. In addition, it is important to note that a vast literature has evolved around development of *fit-for-purpose* approaches (i.e., flexible and pragmatic approaches, see Enemark et al., 2014) to address the increasing demand for information about land tenure in developing countries (e.g., Moreri et al., 2018; Ramadhani et al., 2018; Bennett and Alemie, 2016). These studies provide valuable insights about cadastral system development under strict financial constraints and challenge especially the contemporary cadastral mapping practices.

Besides acknowledging the dynamism of cadastral systems, this dissertation adopts a systemic view in describing and analysing systems of land registration (e.g., Zevenbergen, 2004). In particular, it is stressed that cadastral systems are not just technical systems influenced by technological development but have both a technical and a social dimension (Ottens and Stubkjaer, 2008). This, of course, makes them more complex and uncertain units of analysis. Therefore, this dissertation claims that this kind of system-oriented starting point calls for explorative approaches that do not simply make linear predictions from past data but also aim to increase the understanding of alternative outcomes and related consequences.

Though a general awareness of the need for change exists within the land administration domain, explorations of cadastral-system futures have been conducted with little attention to the theoretical and methodological grounds of the visionary task. This dissertation aims to fill the gaps in knowledge about what drives change in the context of cadastral systems and what kinds of potential alterations can be detected for cadastral systems, looking ahead in time, by integrating concepts and methods from the disciplines of futures studies and socio-technical transition studies. The specific focus of this dissertation is the Finnish cadastral system, which provides a great example of a well-established and reliable cadastral system (WB 2019). Such systems with long traditions and established practices are sometimes referred to as mature cadastral systems (e.g., Enemark, 2009), and this dissertation adopts this definition to distinguish them from developing cadastral systems.

1.2 Research objective, questions and scope

Building on the justification that cadastral systems evolve over time to maintain their relevance and serve the needs of society, this dissertation aims to increase the understanding of the vistas of the future for cadastral systems. Thereby, this dissertation bridges the gap between the cadastral system literature and foresight studies, and the overarching aim can be divided into three separate yet connected research objectives that roughly follow the first three steps of an integrated foresight process (Schultz, 2006): (1) identification of emerging issues of change, (2) examination of the impacts of change issues and (3) imagination of alternative outcomes. To address the objectives, three research questions are formulated:

RQ1: Which emerging issues of change are bound to shape the operational environment of cadastral systems?

The first research question concentrates on identifying drivers of change for cadastral systems. In a global, increasingly complex context, understanding ongoing changes and their interconnections is essential for policy- and decision-makers. Paper I adopts a global perspective for studying the future signals of the land administration domain. By first analysing which future opportunities and challenges the global land administration sector is facing, the paper provides a generalised understanding of the domain-specific emerging issues. The reasoning is that these opportunities and challenges affect, to some degree, every cadastral system worldwide, including the Finnish cadastral system. The domain-specific, global view is complemented in Paper II by a national perspective that explores which widely recognised megatrends are perceived as the most influential ones for the Finnish cadastral system moving towards the year 2035. Williamson et al. (2010) have articulated that – despite their many similarities – the development of cadastral systems reflects "national, social, institutional, legal, and economic circumstances". This implies that the underlying drivers of development should be studied in a national context as well.

RQ2: How do the actors in the land administration sector perceive the implications of recognised changes for the Finnish cadastral system?

The second research question is concerned with understanding how the actors in the land administration sector foresee the impacts of recognised changes on the Finnish cadastral system. *Actors in the land administration sector* refers here to professional parties whose work intersects with cadastral information, be it through the production, use or delivery of the information. *Cadastral information*, then, is defined in this dissertation as authoritative information about land and property interests; in other words, the content of the registers of cadastral systems as well as the cadastral map constitute cadastral information. RQ2 explores the perceived implications from two perspectives. Paper II studies them through the lens of the land administration professionals and by using a

pre-determined list of the most influential megatrends as a starting point. Paper III studies the potential implications from the perspective of the user groups of cadastral information. It should be noted that the implications identified in Paper III are implications derived from the changes recognised in the user groups' own operational environments, so the changes discussed in Paper III should be distinguished from the emerging issues identified through RQ1. Nevertheless, in both papers, the implications are studied in very broad terms since the goal was to encourage the actors to envision potential impacts without anchoring the answers too tightly to the current-day situation.

RQ3: How is the Finnish cadastral system anticipated to develop in the future?

The third research question is concerned with imagining how the Finnish cadastral system may develop in the future. The question is addressed first in Paper III, in which, based on the user groups' views on their future cadastral information needs, some desirable qualities of a future land information system are presented. Hence, the anticipation in Paper III originates from the user perspective. Paper IV, on the other hand, addresses RQ3 by suggesting that integrating concepts from socio-technical transition theory provides a means to study alternative future images of a cadastral system. Paper IV also illustrates the suggested approach and describes three alternative transition pathways for the Finnish cadastral system. It should be stressed that both Paper III and Paper IV approach the anticipation of the future exploratively; the objective is to study what can happen rather than to state what will happen in the future. Therefore, in addressing RQ3, this research follows the scenario paradigm of Mannermaa (1991), who has stated that "a scenario builder seeks to construct several different alternative futures and paths to them".

The scope of the first research question is limited to the operational environment of cadastral systems. *Operational environment* is a concept often used in futures studies to refer to the action space inside which the actor operates (Rubin, 2002). Hence, the term is broad but underlines how the scanning of emerging issues of change should aspire to comprehensiveness. The scope of the second and third research questions is limited to the case of the Finnish cadastral system. Even though many mature cadastral systems share similar features and the underlying rationale for the existence of the systems is the same throughout the world, the current configurations (processes, practices and legislation) make every country a unique case, and the findings are not straightforwardly applicable outside Finland.

Table 1 clarifies the contributions of the research papers to the three research questions. The research questions should not be viewed as completely independent of each other. For instance, the emerging issues of change identified through the first question affect the pathway visions of the third question. Notwithstanding, as this work shows, asking each question independently is important for building a holistic understanding of the topic.

Table 1. Contributions of the research papers to the research questions.

Research question and objective	Paper I	Paper II	Paper III	Paper IV
RQ1 – Identify emerging issues of change	x	x		
RQ2 – Assess impacts		x	x	
RQ3 – Anticipate developments			x	x

1.3 Structure of the thesis

In addition to providing the summary, this dissertation builds upon four research articles. The summary links the papers and their findings together by explaining how each paper contributes to the research questions. **Paper I** explores the future signals of the land administration domain using a quantitative, predominantly automated approach for future signal detection. **Paper II** studies land administration professionals' perceptions of the future of the Finnish cadastral system, i.e., it identifies the most profound driving forces and their expected impacts on the system. **Paper III** studies land administration dynamism from the perspective of the users of the cadastral system and explores what kinds of implications to cadastral system development are stemming from the user side. **Paper IV** introduces concepts from socio-technical transition theory as a means to structure potential development pathways for a cadastral system and illustrates the approach by forming three alternative pathways for the Finnish cadastral system.

Although each paper in this thesis is considered an independent piece of research, the dissertation is based on a wider theoretical and conceptual framework. This framework is elaborated more closely in the following section. The third section covers the methodological grounds of the study by explaining the research design and methods. The fourth section features summaries of the research papers. The fifth section summarises the main findings of the research papers, discusses the contribution of the study, presents an evaluation of the research and offers recommendations of avenues for future research.

2. Theoretical and conceptual framework

Due to the interdisciplinary nature of the dissertation, it is crucial to explain the theoretical grounds and how the dissertation integrates knowledge and methods across disciplinary boundaries. Section 2.1 elaborates the cadastral system concept and shortly reviews studies that have emphasised the dynamism of land and property rights. Section 2.2 continues by introducing the central concepts of future-oriented studies and socio-technical transition theory used in this dissertation.

2.1 Cadastral systems – definitions, purpose and functions

The recording of land- and property-related interests has a long history in developed countries such as Finland. A cadastral system often consists of three basic elements: cadastre, land register and cadastral map. The two registers – the cadastre and land register – list the real property units, other register units and the property rights whereas the cadastral map demonstrates the physical location of real properties (Niukkanen, 2014, p. 63). The term cadastral system is, however, often used in a broader sense, so that it is assumed to include the organisations, actors, procedures and regulations that contribute to the recording of property rights (Larsson, 1991). In this dissertation, the term cadastral system is understood in this sense, and, therefore, cadastral system and land administration system (LAS), which is defined by Enemark et al. (2005) as "the social, legal, economic and technical framework within which land managers and administrators must operate", are treated as rough equivalents in what follows.

The difference, or rather the connection, between a cadastral system and a land information system (LIS) should be clarified as well. An LIS is a subset of geographic information systems concerning data related to land records. Hence, an LIS as a deliverable of a cadastral system provides cadastral information – the basic and authoritative spatial information (Williamson et al., 2010 p. 9) – for both internal and external users. *Internal users* refers here to land surveyors and other professionals working at the cadastral and mapping agency. *External users*, as the name indicates, are employed outside the organisation responsible for the delivery and maintenance of the LIS. The external users can be further divided, for instance, into authoritative and non-authoritative users as is done in Paper III.

In the cadastral literature, much attention has been given to describing the foundation of any cadastral system: the relationship between people and land (e.g., Henssen 1995; Mattsson, 2006). The relationship is explained through the terms *subject* (right holder), *right* and *object* (land area). Paasch (2005) remarks that a direct connection between subject and object rarely exists (this kind of situation is called *open access to land*). Rather, the right acts as a link between the subject and the object. The right in this conceptualisation often refers to ownership rights, but the right may also be, for instance, a customary right, possession, tenancy, landhold, mortgage, usufruct or a restriction related to the object or subject (e.g., Niukkanen, 2014; van Oosterom et al., 2004). Mattsson (2003) has noted that "the rights should be amenable to change", i.e., the connection between subject and object should be dynamic. Altering the rights is not, however, possible without secured rights and trusted information about the subject and object of the right, which leads us to the need for a systematised land recording system (Niukkanen, 2014, p. 17).

Williamson et al. (2010) describe the cadastral system as an engine of land administration with four interrelated functions: land tenure, land value, land use and land development. *Land tenure* is concerned with securing access to land, *land value* with land and property valuation and taxation, *land use* with planning control and land use regulations and *land development* with building new physical infrastructure and utilities, public acquisition of land and expropriation (Enemark et al., 2005; Williamson et al., 2010). For all the above functions to be served, a multi-purpose cadastral system is needed. Enemark (2004) has stated that global drivers such as globalisation and technological development have supported the "establishment of multifunctional information systems with regard to land rights and land-use regulations" to the degree that multi-purpose systems have become a global norm. Williamson et al. (2010, p. 123) have noted, however, that, in German-type title registration systems, such as the Finnish cadastral system, the four functions and related goals are supported by the cadastral system, but historically the functions are not seamlessly interrelated.

Finally, more recently, the academic discourse has shifted towards managing rights, restrictions and responsibilities (RRRs) instead of only rights (see, e.g., Bennett et al., 2008; Paasch et al., 2015; Williamson et al., 2010). The distinction between owners and others is at the centre of this extended approach to managing property and land; whether it is a question of rights, restrictions or responsibilities, the relationship is not just between the benefiting party and the land but also with other parties (government, citizens) that are part of the relationship. Therefore, a more complex set of questions than just "Who owns the property?" or "Where is the land?" may arise, and the cadastral system should be able to provide answers to those questions.

2.2 Towards the future – integrating concepts from futures studies and socio-technical transition theory

This dissertation incorporates concepts from the disciplines of futures studies and socio-technical transition theory to address the research aim. A key for understanding futures studies as a discipline is to assimilate that it recognises multiple futures instead of one. Even though nothing certain can be stated about the future, futurologists believe it is possible to collect information from the past and the present day that can be formulated into alternative images of the future (Bell, 2003). From the perspective of this dissertation, it is important to understand what is meant by a foresight process and how the steps of the process accumulate knowledge about the futures. Schultz (2006) states that a foresight process has five related key activities: (1) Identify and monitor change, (2) assess and critique impacts, (3) imagine alternative outcomes, (4) envision preferred futures and (5) plan and implement change. These combined activities portray the movement and transformation of information collected from the past and present into strategies that picture the preferred future ("a vision"), though it should be emphasised that the last two activities fall outside the scope of this dissertation.

The first activity is often conducted via a scanning exercise. Both terms, *environmental scanning* and *horizon scanning*, are commonly used to describe the systematic examination of emerging issues and events (e.g., Amanatidou et al., 2012). According to a common definition by the UK Government Office for Science, horizon scanning "may explore novel and unexpected issues as well as persistent issues or trends" (Government Office for Science, 2011). Hence, a vast array of foresight concepts, such as weak signals, trends and megatrends, may be associated with horizon scanning. The concepts are closely connected, and the definitions vary by author. In this dissertation, *weak signals* are understood as the first signs of new, emerging issues but with significantly low visibility (Hiltunen, 2010). *Trends*, then, are defined as strong and easily detectable long-term developments (Mannermaa, 2004). Compared to weak signals, the visibility and also the probability of realisation of trends is significantly higher. In this research, *trends* and *strong signals* are treated as synonyms. A trend can also be part of a megatrend. *Megatrends* are larger in magnitude, longer in duration and deeper in their impacts than regular trends (e.g., Mittelstaedt et al., 2014; Naisbitt, 1982). Therefore, megatrends are often understood as developments exogenous to specific domains that cannot be halted or reversed, so, rather than trying to do so, it is more meaningful to explore their potential impacts and start to prepare for them.

The second activity, anticipation of impacts, is a natural follow-up to horizon scanning. It should be clarified that horizon scanning merely produces a list of recognised emerging issues. If some issue or signal, evaluated from a specific domain's, system's or actor's perspective, has no potential impacts, it can be labelled as an insignificant signal no matter how visible and probable the signal may be (Mannermaa, 2004). When the impact anticipation takes place, primary, secondary and tertiary impacts (and so on) can be evaluated. Depending

on the studied issue, statistical computation or qualitative impact assessment techniques can be used for this task (Schultz, 2006). Overall, the goal is to produce a refined understanding of how the different signals impact the studied system.

The third activity, imagination of alternative outcomes, is often called scenario building. A scenario, one of the most well-known but also debated concepts in the field of futures studies, "can denote both descriptions of possible future states and descriptions of developments" (Börjeson et al., 2006). Due to the broad nature of the scenario concept, various scenario typologies have been suggested as well (see, e.g., Bishop et al., 2009; Börjeson et al., 2006). This dissertation adopts the typology of Börjeson et al. (2006), which divides scenarios under three categories: predictive, normative and explorative scenarios. Predictive scenarios attempt to predict what is going to happen in the future, for instance, through forecasts or what-if scenarios. In normative scenarios, a certain future situation or objective is selected as a starting point, and the scenario exercise focuses on how that could be realised. Explorative scenarios, by contrast, aim to explore situations or developments that are seen as likely to happen. Usually, the result is a set of scenarios, and the time horizon for explorative scenarios tends to be long term so that some surprise elements may be included as well (Börjeson et al., 2006).

Börjeson et al. (2006) have argued that explorative scenarios are particularly suitable in cases in which the system and its functioning are moderately well known at present but there is interest in exploring the consequences of alternative developments. The most common way of constructing explorative scenarios is through a two-by-two matrix, in which, after the selection of two key axes of uncertainty, a storyline for each quadrant of the matrix is developed (e.g., Curry et al., 2006). Some scholars have argued, however, that this kind of approach is too simplistic and linear, especially when the scenario subject is a complex system, such as a socio-technical system (e.g., Hofman et al., 2004).[2] As an alternative, scholars of socio-technical studies have suggested merging theoretical considerations from their own discipline, such as the multi-level perspective (MLP) framework, with elements familiar from foresight studies, such as uncertainty, surprise and the presentation of alternative futures (Markard et al., 2009). Socio-technical studies adopting a forward-looking perspective may talk about socio-technical scenarios or transition pathways, depending on the case. This dissertation, following Rosenbloom (2017), uses the term pathway to conceptualise the complex processes and patterns involved with (imagined) transitions into the future.

To fully understand the pathway concept, it is first necessary to introduce the MLP heuristic. The MLP, first introduced by Geels (2002), structures societal dynamics into levels that put pressure on the socio-technical system. In short, the *regime* level describes the ways of realising the societal function in question, the *landscape* level presents societal trends and evolutions that put external

[2] A socio-technical system is defined as a system that consists of social and technical elements and actors. This dissertation perceives cadastral systems as socio-technical systems, following e.g. Ottens and Stubkjær (2008).

pressure on the system and the *niche* level describes protected segments in which novelties (technologies, rules, organisational arrangements, etc.) that challenge the established way of realising the societal function are created and tested. Using the MLP terminology, Foxon et al. (2010) have presented an approach for outlining transition pathways. Figure 1 illustrates this approach.

The socio-technical regime is a key concept in the MLP framework, and it consists of (1) a network of actors and social groups, (2) rules that coordinate and structure the activities of the actors and (3) material and technical elements (Verbong and Geels, 2007). For rules, socio-technical studies use the three-pillar categorisation of Scott (1995) and divide them into regulative, normative and cognitive rules. Regulative rules include explicit regulatory processes, such as laws, formal rules and policies. Normative rules prescribe what is considered as appropriate behaviour, but they are not necessarily formalised in written documents (e.g., values, expectations). Finally, the cognitive pillar describes rules such as shared conceptions, guiding principles and paradigms. Together, these rules coordinate and stabilise the socio-technical regime (Fuenfschilling and Truffer, 2014; Raven et al., 2019).

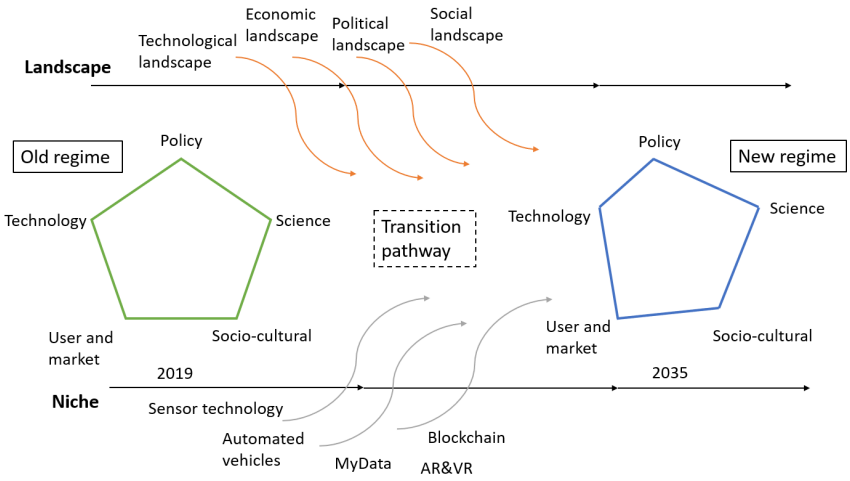

Figure 1. Illustration of transition pathways, following Foxon et al. (2010) and modified to fit the context of this study. Note that the niche innovations that appear in the figure represent only a fraction of the potential innovations.

3. Methodology

This chapter presents the research design and methods of the dissertation. First, however, it is important to outline the epistemological considerations. Two fundamentally different schools of thought, logical positivism and interpretive phenomenology, are distinguished in research (e.g., Amaratunga et al., 2002). The positivist paradigm sees the world as external and objective and believes that the researcher should focus on facts and look for causality and fundamental laws. The phenomenological paradigm, by contrast, sees the world as socially constructed and subjective and posits that the researcher's focus should be on meanings and on understanding the bigger picture. These differences in basic beliefs between the two paradigms affect which methods are considered appropriate for different situations. Logical positivism tests hypothetical-deductive generalisations by using quantitative and experimental methods while interpretive phenomenology aims to inductively and holistically understand human experience in context-specific settings via qualitative and naturalistic approaches (Amaratunga et al., 2002; Sale et al., 2002).

The qualitative-quantitative debate has led to an emerging third paradigm: the pragmatist paradigm. This dissertation is rooted in a pragmatic research philosophy. Pragmatic knowledge claims have been described as problem-centred, pluralistic and strongly tied to the real world (Creswell, 2003). A practical approach is characteristic of pragmatism: "Use whatever philosophical or methodological approach works best for a particular research problem at issue" (Robson, 2002, p. 43). Therefore, pragmatism is often associated with mixed-methods research. The selection of the mixed-methods approach may stem from the following purposes (Greene et al., 1989): (1) triangulation, i.e., looking for a convergence of results from different methods, (2) complementarity, i.e., looking for enhancement or clarification of the results by utilising more than one method, (3) development, i.e., using the results from one method to develop or inform another method, (4) initiation, i.e., looking for paradoxes and contradictions as well as explanations of those contradictions and (5) expansion, i.e., looking to extend the breadth and range of inquiry by using different methods.

This dissertation follows a mixed-method research design with greater emphasis on qualitative methods. In this case, using the typology of Greene et al. (1989) , the reasons for the mixed-method design are complementarity and development –complementarity because addressing issues related to the future, which by definition is unknown, can be done using many different methods and

development because, in this dissertation, the research objectives form a sequence, and using results from one method to inform another method is thus sensible. It should be stressed however, that the development aspect limits to the studies focusing on the Finnish cadastral system (Papers II-IV). Paper I, albeit listed as the first publication in this dissertation, was initiated and written as last one of the four publications. Table 2 summarises the selected methods and data collection and connects the methods to the research questions.

Table 2. Overview of the research methods and data collection.

Research question	Papers	Research methods	Data collection
RQ1 – Identify emergins issues of change	I, II	Text mining Delphi	Abstracts of 5,311 articles A two-round Delphi questionnaire (21+12 respondents)
RQ2 – Assess impacts	II, III	Delphi Thematic analysis of semi-structured interviews	A two-round Delphi questionnaire (21+12 respondents) Semi-structured interviews (19+7)
RQ3 – Anticipate developments	III, IV	Thematic analysis of semi-structured interviews Literature-based analysis; focus group	Semi-structured interviews (19+7) Review of academic and non-academic literature and two focus group meetings

Despite its wide recognition, the mixed-method approach has received criticism too. Bergman (2011) has formulated five critical views on mixed-method research designs: (1) They falsely assume that including an additional perspective qualifies as a justification for the use of a mixed-method design; (2) they falsely assume that including multiple perspectives automatically leads to objective research results; (3) the mixed-method design is misused to reveal the limitations of either qualitative or quantitative methods; (4) the mixed-method design is applied without enough rigor on the individual methods and (5) the mixed-method design involves a limited application of either the quantitative or the qualitative component. Points one through three are addressed next while describing the research design and its justification. As for points four and five, the individual methods and their applications have been evaluated in the peer-review process of each research paper.

The research design consists of one quantitative component (text mining), three qualitative components (thematic analysis of semi-structured interviews, a literature review and a focus group) and one component that has both quantitative and qualitative features (the Delphi method). The components complement one another. Starting with the quantitative component, it provides an objective, quantity-based overview of the trending and also the latent discourse topics – i.e., the future signals – of the land administration domain. The hybrid

component, the Delphi study, acts as a link between the quantitative and qualitative components as it studies the drivers of change through statistical summaries and through insights about their anticipated impacts in a more rigorous manner using content analysis. Finally, the qualitative component contributes by building a holistic understanding of the potential impacts from the user perspective and of the alternatives for a cadastral system transition. Therefore, the research design allows thorough exploration of the research questions, and the employed research methods assist to obtain a fuller picture and deeper understanding of the studied issue. Next, each research method and its selection are elaborated more closely. The implementation and data collection processes are explained in more detail in each study. Also, it should be emphasised that limitations of the employed research methods are discussed as part of the evaluation of the research in Section 5.3.

Paper I is a case study that uses text mining as a research method in the empirical part. Text mining is concerned with language processing, which separates it from many other quantitative methods. In fact, a debate about whether text mining is a quantitative or a qualitative method is still ongoing (Krippendorff, 2004; Yu et al., 2011). In this dissertation, text mining is categorised as a quantitative method due to its data-driven nature (use of algorithms) although the qualitative nature of texts is acknowledged. In essence, text mining is similar to content analysis because the aim is to extract themes and topics by counting words. Yu et al. (2011) have noted that text mining, like many qualitative research methods, "encourages open-mindedness and discourages preconceptions". Therefore, it suits well the aim of Paper I – exploration of emerging issues in the context of land administration – and was considered the most appropriate method for this study. The study used the Scopus database as the source of textual data, and the text corpus was drawn from 5,311 scientific article abstracts. This choice was supported by the fact that the volume of scientific output is constantly growing (Bornmann and Mutz, 2015), but futurologists have noted as well that academic and scientific journals are among the best sources for detecting future signals (e.g., Hiltunen, 2008).

Paper II utilises one of the most well-known research methods in the field of foresight, the Delphi method. The method is based on the argument that N heads are better than one when the goal is to understand complex phenomena, such as anticipation of the future (e.g., Blind et al., 2001). The Delphi method has three main features (e.g., Keeney et al., 2006). First, the study must consist of more than one round of formal questionnaires, and the respondents are anonymous to one another. Second, the study is iterative, meaning that after each round the panellists can re-evaluate their answers in light of the feedback provided. Third, the study presents a statistical summary of the group's responses. There is no fixed optimal size for the expert panel. Instead, finding the right experts and the design and facilitation of the questionnaire are considered as critical steps in the implementation of a Delphi study. Paper II implemented a two-round Delphi questionnaire with 21 respondents in the first round and 12 respondents in the second round. The sampling of potential respondents was based on an expertise matrix, and the goal was to send the invitation to experts

with varying cognitive and social expertise statuses. The Delphi method was chosen due to its participatory yet flexible design, which allows it to be tailored according to the research objective. In this dissertation, for instance, the questionnaire included close-ended and open-ended questions. In the close-ended questions, the panellists were asked to assess the significance and foreseeable impacts of 21 megatrends on a Likert scale. Statistical summaries were drawn from the estimates. In the open-ended questions, the panellists were asked to express more freely their views about the foreseeable impacts. Content analysis was used to examine the responses.

Paper III is a case study in which the empirical part is conducted through semi-structured theme interviews with user groups of cadastral information. The study design is twofold; in the first part, in which the aim was to understand who the users are and why and how they utilise cadastral information, LIS experts from the National Land Survey of Finland were contacted first to get a perception of the current user groups. With the 19 identified user groups, short 10– 25-minute interviews were conducted. Then, in the second part, the focus was on future needs and expectations related to cadastral information, and more thorough interviews were conducted with user groups that were considered to be the most prominent. The author of this dissertation was responsible for conducting all the interviews. At the beginning of each interview the purpose of the occasion was explained, and the participants were told that no personal data would be published. The discussions were recorded after the interviewees' permission for recording was obtained. Notes were taken during the interviews, which were complemented, revised and verified based on audio material afterwards. This material was then used to find emerging themes of future needs and expectations. Semi-structured interviews were chosen as the method due to their flexibility and the ability to reach individual and/or group level perceptions of processes (e.g., Amaratunga et al., 2002).

In Paper IV, a literature review and a focus group were selected as the principal methods. The study design of Paper IV descends from the theoretical framework (MLP and socio-technical change) and has three distinct but complementary phases. The first was dedicated to studying the landscape and niche levels of MLP in the Finnish context through a literature review. The documents were collected purposely with a goal of finding specific information in the documents. The literary sources included both academic and non-academic literature as the reports of practitioners are recognised as good sources for trends that drive current practices in businesses and other organisations (e.g., Retief et al., 2016). Then, two focus group meetings were organised with a focus on the regime level and development of the alternative transition pathways. A focus group is defined as a research technique that collects data through group interaction on a topic determined by the researcher (Morgan, 1996). According to Skop (2006), "group interaction is expected to produce insights that would be difficult to obtain through individual interviews or large-scale surveys". Since the aim of Paper IV was to explore alternative transition pathways for the Finnish cadastral system, the focus group emerged as an ideal method for the purpose. The focus

group was selected purposely and consisted of four land administration professionals with extensive experience within the domain. Two subsequent meetings were held, in June 2019 and in August 2019. Both meetings were recorded after the participants' permission for recording was obtained. The meetings were facilitated by a research group member and notes were taken during the sessions. The author of this dissertation was present at both focus group meetings but was not responsible for the facilitation.

4. Summaries of the Research Papers

This chapter features the research paper summaries (full versions can be found in the Appendices). Each summary presents the objective, methods, main findings and the contribution of the respective paper to the dissertation.

4.1 Paper I: Applying Text Mining for Identifying Future Signals of Land Administration

The objective of Paper I is to provide a comprehensive view of the emerging challenges and opportunities that the land administration domain is facing. The study exploits text mining for the identification of future signals. The study material consisted of the abstracts of 5,311 scientific articles. Following the previous literature on future signal detection with text mining tools (e.g., Lee and Park, 2018; Yoon 2012), the *term occurrence frequency* in documents is used to measure the changes and strength of keywords (*keywords* refers here to a pool of terms that is extracted from the text corpus in a semi-automated manner). In addition, the study uses topic modelling to group sets of keywords together. Topic modelling is used to make the future signals easier to interpret.

The study identifies 19 future signal topics for the land administration domain. The future signal topics are further divided into four categories based on their average term and document occurrence frequencies and change rates: latent, weak, well-known but not strong and strong signals. Three latent signal topics, one weak signal topic, one well-known but not strong signal topic and 14 strong signal topics were observed (see Table 3 for the identified latent and weak signal topics). The findings of Paper I highlight the diversity of emerging issues as the future signal topics range from technology-oriented ones, such as "3D city models in visualisation' and "Advances in image sensors" to environmental and social topics, such as "Sustainable land use promotion" and "Water-related threats". Moreover, topics that could be classified as more traditional land administration topics, such as "Land conflicts", "Responsive and flexible standardisation" and "Participatory land consolidations", were identified. Next, the main findings of the study and their contributions to RQ1 are elaborated more closely.

Firstly, the findings of Paper I uncover the topics that are gaining strength and importance specifically in the land administration discourse. The identified strong signal topics include keywords such as sustainability, conservation, coordination, safety and uncertainty, indicating an increasing awareness of the multipurpose role of cadastral systems. Hence, in the global context, the find-

ings underline how land administration functions have a central role in supporting achievement of the sustainable development goals set for year 2030 (UN 2019). Secondly, in addition to recognising a group of versatile and plausible strong signals, the study finds some interesting latent and weak future signal topics. In particular, the signal topics "National security" and "Plans in digital form" are relevant from the Finnish perspective. Considering the recent change that foreign residents need permission to buy property (HE 253/2018 vp), land is indeed increasingly seen as a critical strategic resource from a national security perspective. The digitalisation of land use planning practices, too, has recently been on the policy agenda (Ministry of the Environment 2019), which confirms that the topic is currently gaining importance in Finland.

Table 3. Weak and latent future signals of land administration (Krigsholm and Riekkinen, 2019).

Topic	Keywords	Interpretation	Category
Non-universal enhancement of location measures	DGPS (differential GPS); ship; arctic; enabling; topology; cartography; collaboration	A ground reference station sending (non-universal) corrections	latent
New data sources for socio-economic variables	NPP (National Polar-Orbiting Partnership); urbanisation; tourism; weather; offshore; shore	Weather and climate monitoring data sources (such as NPP) used increasingly as a proxy to measure socio-economic variables cheaply and in real time	latent
National security	Weapons; treaty; flux; holdings; monetary	Land as a critical strategic resource from a national security perspective	latent
Plans in digital form	Geodatabase; CAD; eplan; georeferenced; thematic; GIS; software	Advances in the common GIS software to enable digitising and planning documents	weak

Thus, it may be concluded that the main contribution of Paper I is the framing of the discussions about land interests and their recording. The framing goes beyond the results of a typical literature review as, because it is a horizon scanning exercise, special attention is given to quantifying the changes and strength of the emerging topics. Therefore, the results of Paper I benefit both academics and practitioners globally by providing objective, literature-based evidence of the topics that are gaining momentum at present.

4.2 Paper II: Understanding the Future of the Finnish Cadastral System: A Delphi Study

This paper investigates how land surveying professionals perceive the future of the Finnish cadastral system. Building on a list of 21 widely recognised megatrends (Z_punkt 2016), the study aims to elaborate their relevance and potential impacts from a cadastral system point of view. A two-round Delphi survey was conducted to collect the experts' views on the topic. An expertise matrix was used to identify potential Delphi panellists to assemble a panel with varying cognitive and social expertise statuses. The final sample of respondents consisted of representatives of the National Land Survey of Finland, municipalities, the private sector and research institutions. The areas of expertise (as determined

by the respondents themselves) varied from real estate appraisal and cadastral surveys to land use planning and credit granting and collaterals. The number of respondents in the first round was 21 and that in the second round 12.

The panellists were asked to evaluate the relevance of each megatrend on a Likert scale including "not relevant", "relevant" and "highly relevant", scored as 0, 1 and 2, respectively, in the analysis. Based on the scores, the relative importance of the megatrends was assessed through means and standard deviations. Two megatrends from the technological category – digital culture and ubiquitous intelligence – were perceived as the relatively most important ones. The eight relatively most important megatrends are listed in Figure 2. Looking at the list, it may be noted that, although technological megatrends make the top of the list, the subsequent megatrends represent other categories, namely economic, political, social and environmental megatrends.

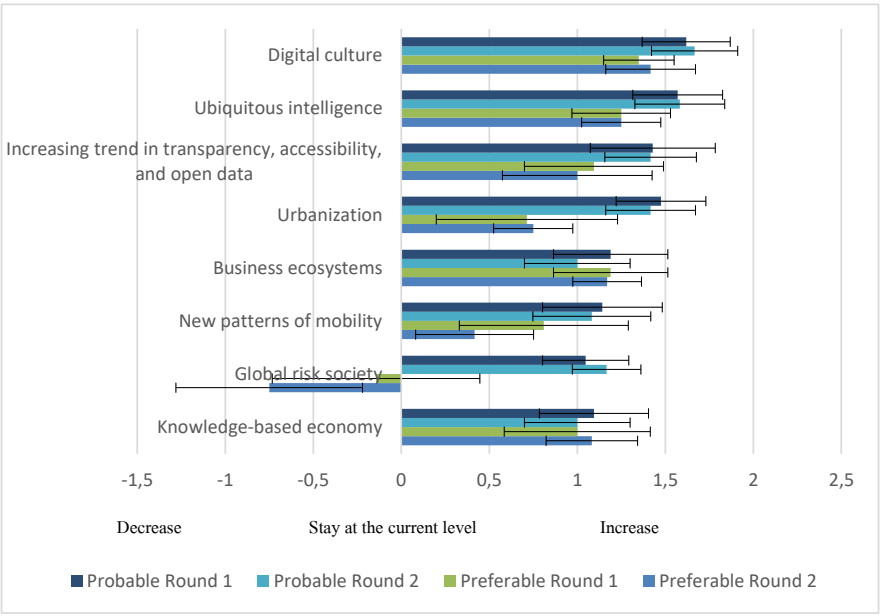

Figure 2. The eight most relatively important megatrends and their probable and preferable impacts assessed on a Likert scale from -2 to 2 (Krigsholm et al., 2017).

In addition to the relevance, the panellists were asked to evaluate the probability and preferability of the impacts of the megatrends on a 5-point Likert scale ranging from -2 to 2. The negative values corresponded to a decreasing impact by year 2035, zero to an unchanged impact and the positive values to an increasing impact. Figure 2 summarises the Likert-scale perceived impacts for the eight relatively most important megatrends. In sum, the potential impacts of the megatrends were perceived as both probable and preferable with one exception, as the megatrend of "Global risk society" was considered to generate unpreferable impacts on the Finnish cadastral system. The findings also show that, for many of the considered megatrends, the probability of the impacts was assessed higher than the preferability of the impacts.

To gain more insights on how the megatrends impact the Finnish cadastral system (RQ2), open-ended questions were asked as well through which the respondents were more freely able to elaborate their views. These answers were condensed under one to three key points (Table 4). Some of the anticipated impacts are more specific, such as "Building and planning information as part of the cadastre" and "Privacy protection and possible conflicts with open data", whereas other perceptions merely trigger a set of new questions. For example, in relation to economic megatrends ("Business ecosystems" and "Knowledge-based economy"), new innovations arise as a potential impact, but drawing conclusions from that is difficult. Particularly, the increasing trend towards transparency, accessibility and open data was expected to yield some profound and interesting implications to the Finnish cadastral system as the respondents brought up new forms of public services, interfaces with other public data sources and the diminishing need for parallel cadastres as related key impacts.

This study provides a comprehensive picture of how experts in the field of land administration perceive the wider, exogenous developments and their impacts on the cadastral system. The study contributes to RQ1 by providing a collective image of the megatrends that are particularly important from the perspective of the Finnish cadastral system. It appears that Finnish land administration professionals emphasise technological developments as the main drivers of change. However, the image is not that one-sided as a group of economic, political, social and environmental megatrends are foreseen as influential as well. The study also contributes to RQ2 by further examining how experts perceive the impacts of the megatrends moving towards the year 2035. The statistical summaries of the anticipated impacts reveal that the impacts are seen as more probable than preferable, which indicates a slight resistance to change among the Delphi panellists. The open-ended answers, in contrast, create a more positive outlook on the potential impacts of the megatrends as future opportunities are brought up over challenges. Overall, the study contributes by building knowledge of long-standing, exogenous developments (i.e., megatrends) that call for attention from a cadastral system point of view as well as knowledge of their potential impacts. Assessing signals from the perspective of a system increases the understanding of which signals are significant and which less so. This kind of knowledge is important for both academics and practitioners.

Table 4. Anticipated impacts of the eight relatively most important megatrends summarised (Krigsholm et al., 2017).

Megatrend	Anticipated impacts	Examples of quotations
Digital culture	- More convenient use and exchange of information	"Spread of digital culture: The ways in which people want to use (cadastral) data and benefit from it will change and diversify in the future." "Digitalisation and open data are the most significant drivers of change."
Ubiquitous intelligence	- Better and faster public services	"The cadastre should be integrated with different web interfaces and in the future with different virtual realities." "The development of technology and ubiquitous intelligence will pave the way to a higher standard of services."
Increasing trend towards trans-	- New forms of public services	"People will start maintaining information themselves. Transparency and digitalisation will together provide register data that is open and accessible to everyone. People

parency, accessibility and open data	- Interfaces with other public data sources - "Parallel" cadastres should become unnecessary	can either correct inaccuracies themselves or give feedback about inaccuracies, which will improve data quality." "The authoritative surface will disappear and users of cadastral data will not even know where the data is coming from. All that is required is that the data is real time, reliable and easy to use."
Urbanisation	- Building and planning information as part of the cadastre - True 3D - Higher volume (more real property units)	"Urbanisation will increase demand for 3D cadastral information." "Urbanisation will significantly increase the number of cadastral units. At the same time, demands for cadastral data accuracy will increase."
Business ecosystems	- New innovations - Shared processes and new forms of collaboration	"Opportunities to develop new applications that serve the owner (of a real property), the buyer, the real estate agent and the lender." "The cadastral system must support new innovations." "It will become necessary to have good cooperation between the public and private sector. A clear division of labour will also be needed."
New patterns of mobility	- Smart transportation as part of cadastral data collection - International standards and harmonisation of cadastral data - Fully coordinate-based cadastres	"The development of smart transportation with new location systems will also bring benefits for the cadastre and its digitalisation. Coordinate-based real properties will become conceivable."
Global risk society	- Cybersecurity threats - Privacy protection and possible conflicts with open data	"The cadastral system must function reliably regardless of time and place and provide a basis for other digital services. We need to be better prepared for information and cybersecurity threats."
Knowledge-based economy	- Crowdsourcing/voluntary geographic information - Cadastre as a source material for new innovations	"Economic pressure, improved customer experiences and advances in technology will require the use of crowdsourcing." "Knowledge producers and perhaps even individual users will become involved in maintaining the cadastre."

4.3 Paper III: The Changing Uses of Cadastral Information: A User-Driven Case Study

This paper aims to understand land administration dynamism from a user point of view. The study design was twofold. The first part was designed for simply understanding who the users of cadastral information are, how they use the information and, most importantly, why they need cadastral information. For this part, 19 representatives of cadastral data user groups were interviewed through short, 10–20-minute phone interviews. After an overview of cadastral data usage in Finland is laid out, the second part of the study zooms in on the user groups' perceptions of their future land information needs: what kinds of major changes they detect in their own operational environment and how they are expected to affect information needs. The ones that are considered to be broader, society-level changes are then translated into implications for the land administration system (LAS). For this part, seven semi-structured interviews that lasted between 40 and 60 minutes were conducted.

The study recognises four main themes of cadastral data usage: (1) land use and environment, (2) markets and valuation, (3) governance actions and (4) juridical decision-making. This information was used as a criterion for selecting interviewees for the second round, i.e., at least one representative for each theme was included. The sample of second-round interviews included one representative from each of the following groups: the banking sector, construction and infrastructure companies, the Regional State Administrative Agency, municipalities, real estate consultancies, the Population Registration Centre and the Tax Administration. Moving on to findings that contribute to RQ2, the study first of all identifies six major changes in the user groups' operational environments that are expected to impact the LAS as well (Table 5): (1) Streamlining environmental permit procedures, (2) integration of public services, (3) 3D land use planning, (4) tightening banking regulations, (5) e-government and new digital services and (6) data transmission between public data agencies. The LAS implications are derived from these changes as they can be anticipated only after the user groups describe how their own operations/functions are about to change in the foreseeable future.

Table 5. LAS implications derived from the future cadastral information needs of prominent user groups (Krigsholm et al., 2018).

Identified change	Identified by	Implications for LAS
Streamlining environmental permit procedures	E	- Less need for information about ownership and rights of use
Integration of public services	E	- Increased demand for high-quality aerial photos and greater emphasis on the temporal aspect of information
3D land use planning	M, C	- Cadastral information should be available in 3D format - The temporal aspect becomes more important.
Tightening banking regulations	B, R	- Land register content must be up to date and reliable - Cadastral information must be easily connectable with data from other sources
E-government and new digital services	B, C, E, M, P, T	- Increased demand for electronic contact information - Increased demand for planning information as part of LAS
Data transmission between public data agencies	P, T	- Roles and responsibilities of different public data agencies should be well defined - Finding common terminology and basic units

B=Banking sector, C=Construction and infrastructure companies, E=Regional State Administrative Agency, M=Municipalities, R=Real estate consultancies, P=Population Registration Centre, T=Tax Administration.

Therefore, the findings reported in the third column in Table 5 especially contribute to the second research question. Streamlining environmental permit

procedures, for example, is expected to lead to a decreasing need for information about ownership and rights of use due to a shift from the processing of environmental permits to the monitoring of areas. This is because monitoring does not require a heavy notification procedure, unlike the processing of environmental permits. The relevance of the temporal aspect of cadastral information can also be detected in the results. The integration of public services, 3D land use planning and tightening banking regulations all stress this aspect in some form or another. Moreover, calls for 3D-format cadastral information were made, although there was also some hesitance related to the added value of 3D representation and discussions about who should be the "transition leader" on this front. Unsurprisingly, almost all the interviewees emphasise the increasing significance of digital services, which from an LAS point of view implies a higher demand for electronic contact information and for planning information. Finally, the key implication stemming from the change factor "Data transmission between public data agencies" is the need to clarify the roles and responsibilities of different public data agencies.

Moving on to the contribution of the findings to RQ3, the results of this study also produce some guidelines for LAS development when the LAS implications are drawn together. This study suggests that, from the user point of view, the success of the future LAS comes down to three qualities. Firstly, the LAS should be dynamic and responsive. The cadastral information, especially the land register content, needs to be up to date and the related services (LIS in particular) need to match the general standards of information services. Secondly, the LAS should be interoperable, i.e., easily accessible by other technologies and applications. Information interchange between actors from different sectors is expected to increase, but it is seen that current, single-industry domain models hinder this development. Thirdly, the LAS operations and information content should be coordinated with other public data registers. This suggestion extends to avoiding duplicates and other inconsistencies but also to building a model for a more coherent system of public data functions.

To conclude, Paper III introduces a user group perspective to study land administration dynamism. The perspective has received a limited amount of attention in the previous literature. The study shows that, though the interviewees present a diverse group of cadastral information users, the LAS implications derived from the user groups' expected future information needs harmonise to a great extent. Overall, the study reiterates the need for an interoperable, accurate and reliable LAS.

4.4 Paper IV: Pathways for a Future Cadastral System: A Socio-Technical Approach

The main objective of Paper IV is to examine how concepts from socio-technical transition studies can be used to structure potential pathways for cadastral systems. Ultimately, the study builds on a notion of Ottens and Stubkjaer (2008),

who have proposed that cadastral systems can be described and analysed as socio-technical systems. The study starts with an extensive review of the literature on socio-technical transitions, and the MLP framework in particular, since this kind of approach has not previously been used to study cadastral system futures. The theoretical foundations of Paper IV are summarised in Figure 1 (Section 2.2.), which pictures the three levels – the niche, regime and landscape levels – of the MLP framework as well as the core notion of socio-technical change: that transitions of socio-technical systems take place on the regime level. At the regime level, regulative, normative and cognitive rules coordinate and structure the activities of actors across the five regime dimensions: the technology, science, policy, socio-cultural and user and market regimes (Verbong and Geels, 2007).

The key for the formulation of alternative transition pathways is first to build a depiction of each MLP level. The research process of Paper IV was designed with this lesson in mind. The approach is illustrated by a case study of the Finnish cadastral system. In the first phase, landscape developments and the most auspicious niche-level innovations were identified from literary sources. Then, in the second phase, the current regime and its dynamics were studied in a focus group setting. In addition, the main drivers from both the landscape and niche-level were identified in the second phase, and these outputs were used as preconditions for alternative pathway formulation. Finally, in the third phase, the three pathway variants were complemented and agreed upon during a second focus group meeting. The focus group was purposely selected and consisted of four land administration professionals with extensive experience within the domain.

The landscape of the Finnish cadastral system is portrayed by four landscape developments – the technological, economic, political and social landscapes – while the niche-level is presented through a list of 19 (social and technological) innovations. Moving on to the regime description, the focus group participants agreed that, in the case of the Finnish cadastral system, it is reasonable to handle technology and science as one instead of two separate regime dimensions. Altogether, the policy, socio-cultural and user and market regime dimensions were considered to be more important ones than the science and technology dimension when the focus was on the underlying rules of the system. Technology, in particular, was seen more as a supporting and enabling element whereas rules such as perceptions of what "the market" wants and the acceptance and reliability of cadastral information were seen as fundamental rules that provide, in the long run, better opportunities to contemplate regime transitions.

The three alternative pathways (Table 6) form the main findings of Paper IV. The contribution to RQ3 stems from the pathway variants. For each variant, a narrative storyline was developed that describes the key changes, the related concepts, the key actors and examples of design and operation implications as well as the key challenges. In the first pathway, "Cadastral system under digital transformation", rapid digitalisation that extends to all sectors of society pressures the cadastral system from the landscape level, leading to two key changes: a shift towards a digital service ecosystem and automation of decision-making,

especially in cadastral survey proceedings. Particularly, the challenge of understanding the effects of digitalisation on all processes was brought up by the focus group participants. The second pathway, "Differentiating urban and rural cadastral systems", originates from demographic changes, namely urbanisation and the aging of populations. The key changes of this variant are an asymmetrical development of urban and rural cadastral systems and the adaption to new forms of land tenure. The realisation of the first change depends heavily on political decision-making. If the political will is in favour of a unified solution for the whole country, this variant is inconceivable. The third pathway, "Cadastral system facing new data management challenges", builds on two developments: the increasing threat of cyberattacks and the MyData movement. Therefore, in this pathway, the Finnish cadastral system is going through the following changes: (1) a cross-national back-up mechanism is established, (2) cross-national regulation increases and (3) users of cadastral information show interest in having stronger control over their own data. Related challenges include, for example, controlling the conflict between openness and personal data management and a lack of expert knowledge about the new kinds of security threats.

Table 6. Selected aspects of the pathway variants adapted from Krigsholm et al. (2020).

Pathway aspect	**Pathway 1: Cadastral system under digital transformation**	**Pathway 2: Differentiating urban and rural cadastral systems**	**Pathway 3: Cadastral system facing new data management challenges**
Key changes	A shift towards a (digital) service ecosystem; automation of decision-making and cadastral survey proceedings	Asymmetrical development of urban and rural cadastral systems; adaption to new forms of land tenure	Increasing importance of cross-national regulation; a cross-national back-up mechanism; users with stronger control (or interest in having control) over their own data
Key challenges	Understanding the effects of digitalisation on all processes; policy-makers in a key role in recognising relevant niche innovations; traditions and other lock-ins; system resistance and maintenance of trust; finding a shared vision within/for the network	Increasing complexity and volume of RRRs (in urban areas); anticipating the pace and scope of a changing customer base; dependence on political decision-making (regional politics, etc.); integrating properties and buildings as part of the cadastral system	Risk management; controlling the conflict between openness and personal data management; lack of expert knowledge; communications during crisis; widespread effects in an increasingly networked environment

In sum, Paper IV suggests that understanding cadastral system futures requires, in addition to acknowledging the most profound exogenous driving forces and the most prominent rising innovations, a sense of the underlying rules of the game. Previous studies (e.g. Lin et al., 2015) have also suggested that cadastral system development tends to be gradual and path dependent. This is,

however, the first study that extends the analysis from past and present to potential future developments. Therefore, the findings provide new insights for discussions of the future of mature cadastral systems.

5. Discussion and Conclusions

5.1 Summary of the research

This dissertation aims to increase understanding of the vistas of the future for cadastral systems. To address the aim, three research questions were formulated.

The first question studied the emerging issues and drivers of change in the operational environment of cadastral systems. Abstracts of scientific articles and land administration professionals' answers to a Delphi questionnaire were used as study material. Through the text mining exercise, four kinds of future signal topics for the land administration domain were identified: latent, weak, well-known but not strong and strong signals. The identified future signal topics cover a broad variety of issues ranging from climate change mitigation and land conflicts to flexible standardisation and advances in surveying technology. Overall, the findings emphasise the need to address the future of land administration and cadastral systems from a holistic perspective. Although this is a very general finding, it raises an interesting question: How multi-purpose is the future of cadastral systems and of the Finnish cadastral system in particular? Many of the strong future signals identified in Paper I relate to sustainable land use, connecting them more closely to the social and environmental objectives of land administration. In the case of mature cadastral systems, such as the Finnish cadastral system, the economic objective of recording land interests (i.e., the land market perspective) has traditionally been in a central role. It should be interesting to follow how the roles of other objectives, e.g., the social and environmental ones, develop in the future.

The drivers of change were explored also from a national perspective as a Delphi panel was assembled of Finnish land administration experts. The findings imply that the Finnish experts emphasise the role of technological advances in cadastral system development as "Digital culture" and "Ubiquitous technology" were voted as the most significant megatrends from a cadastral system perspective. However, the subsequent highly significant megatrends in the ranking order represent economic, political, social and environmental megatrends. This observation hints that the overall perception of the drivers of change is not entirely black and white.

The findings to the first research question are mostly in line with the previous literature. For instance, advances in surveying technology, such as cadastral mapping using unmanned aerial vehicles (Fetai et al., 2019) and participatory methods of cadastral information collection (Rahmatizadeh et al., 2016), have

been increasingly discussed in the academic literature. Further, urbanisation, which was reckoned as the fourth most important megatrend in the context of the Finnish cadastral system, is commonly recognised as the main driver of the need for multi-dimensional cadastral information. It should be stressed, however, that the Finnish experts had mixed perceptions of the preferability of the impacts of urbanisation on the cadastral system. This may have reflected negative tendency towards urbanisation development in general amongst some of the experts, not just in the context of cadastral systems.

The second question studied how the changes on the horizon of the Finnish cadastral system and also on the horizon of the users of cadastral information are perceived to impact the cadastral system. The question was explored using qualitative research methods. First, the impacts of the eight relatively most important megatrends were studied, and it was concluded through statistical summaries that the anticipated impacts are considered less preferred than probable. This is somewhat contradictory to the results derived from the open-ended questions, which indicated that the impacts can be viewed more as opportunities than as threats. For example, advances in technology were expected to prompt new innovations and better public services. Interestingly, a common perception was that technological megatrends shape the way in which people will want to use cadastral data. This view was linked, for example, to the increasing capabilities of mobile devices and cloud services. A megatrend called "Increasing transparency, accessibility and open data" was assumed to result in new forms of public services, interfaces with other public data sources and a decreasing need for parallel cadastres maintained by other public data agencies than the land register authority.

Then, the impacts were studied from the perspective of cadastral data user groups by outlining first the expected changes in cadastral data usage. The implications drawn from the expected changes reveal some interesting insights. First, several user groups expect the temporal aspects of cadastral information to grow in importance in the future. Temporality refers here to the availability of historical records and to the up-to-dateness of, especially, the land register content. Second, the importance of defining the roles and responsibilities of different public data agencies was brought up by some of the authoritative user groups, which complements the findings of Delphi study. Third, the growing role of new digital services – a change identified by a majority of the interviewees – is expected to lead to a higher demand for electronic contact information and for planning information.

Previously, the temporal aspects of cadastral registration had been discussed mainly in studies concerning 4D(/5D) cadastres (e.g., Döner et al., 2010). An analysis by Döner et al. (2010) suggests that the implementation of a 4D cadastre is possible from legal, organisational and technical perspectives. The question remains, however, of what are the actual needs for a 4D cadastre in relation to the costs. Ho et al. (2018) have studied 3D geo-information from a public-value perspective and note that a "lack of direction may impede investment in and adoption of 3D geo-information". The findings of this dissertation support this view as some of the user groups that brought up the potential need for 3D-

format cadastral information also contemplated who should take the initial actions towards 3D representations.

Finally, the third question studied how the Finnish cadastral system is anticipated to develop in the future. The question was addressed from two angles as it was first approached from an LIS perspective and then explored by forming alternative images of the future of the Finnish cadastral system. The user group perspective adopted in this dissertation provides a glance on the future expectations related to the Finnish LIS. As a deliverable of the cadastral system, the LIS expectations translate to wider guidelines for cadastral system development as well. This dissertation concludes that the system should be (1) dynamic and responsive, (2) interoperable and (3) coordinated with other public data registers. Though none of these qualities is prioritised over others in this research, it may be argued that the third one is perhaps the hardest to put into practice due to the established structures and long-standing traditions of public sector register-keeping.

The anticipation was continued in an illustrative case study that leans heavily against concepts from socio-technical transition theory. Building on the MLP framework, this dissertation presents three alternative transition pathways for the Finnish cadastral system. Each pathway is presented through a narrative storyline. The first pathway, "Cadastral system under digital transformation" depicts a shift towards a digital service ecosystem and the automation of decision-making in cadastral survey proceedings as the key changes. The second pathway, "Differentiating urban and rural cadastral systems", envisions an asymmetrical development of urban and rural cadastral systems, which becomes concrete especially through higher position accuracy and wider information content in urban areas. The third pathway, "Cadastral system facing new data management challenges", is built around increasing global security threats (cyber threats in particular) and a personal data management movement called MyData that promotes individuals' stronger control over their own data.

If the main characteristics of the pathways are considered in light of the previous literature, both similarities and dissimilarities can be found. The requirement of interoperability across different sectors (e.g., Kalantari et al., 2008) as well as the need for more networked register authorities (e.g., Macharis and Crompvoets, 2014) have been addressed before. Also, the platform management concept in the case of spatial data has been discussed before by Jabbour et al. (2019). Regarding the dissimilarities, this study speculates on the effects of demographic changes on a mature cadastral system to a degree that no prior study has reached. Further, the third pathway challenges the conception of cadastral systems as national registers, which is a new insight in these discussions.

Collectively, the findings of this dissertation suggest that the future of cadastral systems is a complex and holistic issue. The research was designed in such a manner that the individual research papers complement one another and that the results of previous studies guided the development of subsequent studies. Again, it should be emphasised that the guidance limits to studies that focused on the case of the Finnish cadastral system. Therefore, strong connections can be made between the findings of RQ1 and RQ2 and the images of the future. To

start with, the main drivers of the three pathways are digitalisation, demographic changes (urbanisation in particular) and global security threats combined with changing personal data management preferences, which to a great extent are derived from the findings of RQ1. Several of the anticipated impacts connect to the pathway variants as well. For instance, the expected coordination between public data agencies materialises in the form of the digital service ecosystem in Pathway 1. The interoperability and multi-dimensionality of cadastral information, on the other hand, are key design and operational aspects related to Pathway 2. Finally, in Pathway 3, maintaining the reliability of cadastral information is in a central role – a commonly acknowledged requirement of authoritative information but also a need recognised from the user perspective in this research.

5.2 Contribution of the research

Research in land management has traditionally drawn from multiple disciplines, such as law, engineering and the social sciences. This dissertation contributes to academic research by adopting a forward-looking perspective and integrating concepts and knowledge from the disciplines of futures studies and socio-technical transition studies. The previous literature has acknowledged the dynamic nature of cadastral systems and the advisability of monitoring the changing needs stemming from the surrounding society, yet the explorations of the future have been limited mainly to certain technologies and their impacts on some specific aspect, such as cadastral survey proceedings, data models or legislation. This research, in contrast, sees "cadastral foresight" as a holistic and nuanced issue that to be adequately addressed requires the incorporation of new perspectives and methods. To that end, this dissertation expands the scope and rigor of research on cadastral system dynamism.

Until now, information about cadastral-system–relevant trends and emerging issues has been fragmented. This dissertation provides a refined and revised understanding of what drives change in the context of cadastral systems. It provides empirical evidence of the emerging issues of change – of both the issues that have received less attention to date (i.e., weak and latent signals) and the better known, forceful issues (i.e., strong signals and megatrends). The methods that the dissertation applies to the detection of emerging issues are novel in the field. Delphi is an established and widely used method in foresight studies but is rarely applied in the context of cadastral systems. Also, to best of author's knowledge, text mining applications are scarce in the field. Although the size of the text corpus in Paper I is moderate, the analysis goes beyond typical content analysis as it measures term co-occurrences and shows which terms are gaining strength at present. Further, Paper I contributes to the strand of non-participatory future signal detection studies (e.g., Lee and Park, 2018; Yoon 2012) by showing that using topic modelling in the analysis decreases the ambiguity and abstractness of the identified future signals.

This study also brings the often-neglected user perspective on cadastral systems to the discussion. Thus far, the user perspective has been mainly a buzzword brought up on a regular basis. That is surprising since the changing role of public services has been discussed for a while now (see, e.g., Denhardt and Denhardt, 2000). By looking at cadastral system dynamism from the user perspective, the findings are not restricted by what the internal actors (or the researcher) assume to be significant. Instead, the findings should reflect what kind of information the user groups regard as relevant and important in their own work. Paper III also highlights that, though external user groups form a relatively heterogenous cohort, their expectations about future cadastral information needs harmonise to a great extent.

The cadastral literature has been lacking examples of systematic and theoretically sound scenario studies, and this dissertation addresses that gap. The research integrates theoretical knowledge from socio-technical transition studies to structure the exploration of alternative pathways for cadastral systems. The approach is demonstrated by an example of the Finnish cadastral system, and the formulated alternatives contribute to the knowledge base of potential transitions of mature cadastral systems. Further, this research argues that, instead of focusing on individual innovations or technologies, more emphasis should be put on understanding the whole system and especially the "deep structure" that coordinates the functioning of the system.

The study makes practical contributions as well. The findings of this research can be applied to support decision-making in organisations within the land administration domain. Strategic level decision-making, in particular, benefits from findings that embrace the uncertainty related to the future. Though the emphasis was on the uncertainty and exploration of potential developments, the study detected some tangible expectations related to the development of the Finnish cadastral system as well. For instance, addressing the insufficient accuracy of property division on the cadastral map, and the policy-driven target of an automated upkeep of registers, are very concrete goals to pursue. Overall, the findings of this dissertation imply that decision-making related to land and property interests and their recording in general must be cautious and well reasoned because great financial, ecological, social and other interests depend upon land.

5.3 Evaluation of the research

Validity and reliability are standard notions associated with the evaluation of all research (Eisenhardt, 1989; Yin, 1994). Robson (2002, p. 176) adds generalisability as a third criterion for the evaluation of flexible (qualitative) research designs. Next, the present study is evaluated in consideration of these three criteria. The evaluation presented in this section is targeted at the methodology and the overall findings. The quality of the research in the individual research papers has been addressed in the respective papers.

Validity is a very broad and abstract notion that is often related to the accuracy of an answer provided by research (Amaratunga et al., 2002; Robson, 2002). In Robson's (2002) categorisation, validity is limited to internal validity. Internal validity refers to the correctness of the cause-and-effect relationships established in the study (e.g., Amaratunga et al., 2002), though Yin (1994) remarks that, in exploratory research, internal validity concerns the broader problem of making inferences. Common strategies to increase internal validity include prolonged involvement, triangulation, peer debriefing and support, member checking, negative case analysis and an audit trail (Robson, 2002). This dissertation has attained internal validity especially through triangulation, peer debriefing and support and an audit trail.

Triangulation refers to the use of multiple sources to enhance the rigor of the research and can be further distinguished as data triangulation, observer triangulation, methodological triangulation and theory triangulation (Robson, 2002). Triangulation is described as a valuable and widely used strategy by Robson (2002, p.174), since it helps to counter multiple threats to validity: validity of the findings, researcher bias, as well as respondent bias. As Patton (1999) has noted, triangulation is a way to establish the consistency of findings and to find explanations for inconsistencies. This thesis uses data triangulation and methodological triangulation; i.e., more than one method of data collection was used, and the dissertation combines quantitative and qualitative approaches. Furthermore, in the focus group meetings, observer triangulation was used as three members of the research team were present at both meetings. Peer debriefing is defined as a process in which one's inferences are exposed to a colleague or peer during the research, and it especially reduces the threat of researcher bias (Robson, 2002, p. 174). All the research papers in this dissertation were co-authored and carefully reviewed by the other authors. In addition, Papers III and IV were peer debriefed in research seminars held at Aalto University. The research papers were reviewed by anonymous reviewers before publication in the academic journals. Audit trailing simply means keeping a record of activities during the research process. The interview and focus group records (both written notes and audio tapes), the Delphi survey questionnaire, the data sets (survey data and Scopus data) and the R code scripts form the audit trail material of this dissertation. The interview records and other documentation were stored in cloud storage, and only the principal authors had access to the documents.

Triangulation reveals that the findings from the different research components show some inconsistencies especially regarding the drivers of change of cadastral systems. The findings from the quantitative component, i.e. the text mining exercise, indicate a strong emphasis of social and environmental factors for the future cadastral systems. The findings of the Delphi study, in contrast, put a higher weight on the technological megatrends and their potential impacts. It can be argued that this observation reflects both the strengths and weaknesses of these research methods. Text mining, for instance, is often praised for its objectivity, replicability and ability to summarize information from large amount of textual data. The flip side is, however, its inability to assess the contextual and conceptual fit of the analysed bag of words. The Delphi, on

the other hand, as an expert-based method builds upon the expertise of the selected panel, both in positive and negative sense. The findings of a Delphi study always reflect the choices and preferences of a relatively narrow group of experts which is a clear limitation. However, at the same time, the Delphi method, like qualitative research methods in general, is sensitive for detail and context, which should ensure that the findings reflect a deeper understanding of the specific case of the Finnish cadastral system.

Reliability, according to Yin (1994), refers to the repeatability of research, and the goal of reliability is to minimise the errors and biases in a study. Robson (2002, p. 176) notes that being able to show others that the research has been thorough, careful and honest is the best way to increase reliability within flexible research designs. The above described audit trail supports this goal as well. Further, the design of the Delphi questionnaire follows the principles of the method, and the implementation is reported in a detailed manner in Paper II; thus, other investigators could repeat the study by following the steps of implementation. Paper I explains the steps of data collection in detail, the data is drawn from a scientific article database (Scopus), and the text mining tools that were used in the analysis are reported and explained in the study. Hence, researchers with access to the database may replicate the text mining exercise. Regarding the data analysis and reporting of the qualitative components, in order to avoid misrepresentation of the participants' views, the findings (or sub-findings, depending on the research design) were shared with the participants.

Robson's (2002) third criterion, generalisability, is equivalent to external validity of the research. Amaratunga et al. (2002) state that external validity refers to the generalisability of the findings beyond the research sample and/or setting in which the research took place. Since generalising the results is not a primary goal in the context of qualitative research, the concept of transferability is more often adopted. Transferability refers to the extent to which the findings of the research can be transferred to other contexts (Lincoln and Gupa, 1985). Both the transferability of the research methods and the transferability of the results deserve consideration. A detailed description of the methodology is provided in each paper, which enhances the transferability of the research methods. The transferability of the results can be considered from the perspective of (1) the representativeness of the samples and (2) the transferability of the findings to other contexts.

Starting with the representativeness of the samples, in Papers II, III and IV the sample sizes remain limited, and the selection of the samples was purposeful. In Paper II, 150 individuals were invited to take part in the Delphi panel, making the response rate modest (14% for the first round). Participation to the panel was voluntary and, therefore, even though an expertise matrix was used to identify potential panellists, the sample was not as representative as the initial goal intended. The assumption is that the final sample was biased, at least in the sense that individuals who see the future more as an opportunity than as a threat were more likely to respond to the questionnaire. In Paper III, the sample of the first-round interviews covered 19 user groups, but in the second round

it was reduced to seven. The idea was to include diverse views (representing different use themes and both authoritative and non-authoritative user groups), but the sample selection would have benefitted from operational level data of the actual cadastral information retrieval numbers. However, it should be noted that having exact information about current-day data usage does not guarantee that the same user groups will be the ones using cadastral information in the future. In Paper IV, the assembled focus group consisted only of four participants. The number is low, but the sampling in this study follows the principle of segmentation that ensures more fluent facilitation of the discussions as the participants share similar features (Morgan, 1996), in this case a shared professional background in the field of land administration (more about the focus group sampling in Krigsholm et al., 2020).

Moving on to the transferability of the findings to other contexts, in Paper I the findings are global, and the question is more concerned with how transferable the results are to national contexts. The significance of each future signal, at least, is likely to vary from country to country. In Paper II, the studied megatrends are global, yet they are assessed from a national perspective. However, considering the similarity of mature cadastral systems and the fact that, historically, the development of cadastral systems has followed similar phases (Ting and Williamson, 1999), it could be argued that the findings offer insights to academia and practitioners outside Finland as well. The same applies to Paper IV, in which, in a similar vein, the recognised landscape developments were derived from global megatrends. The identified niche-level factors were more country specific as they were drawn from documents published by the Finnish Parliament's Committee for the Future. However, as the results of Paper IV show, the niche-level factors have a smaller impact on the formulated pathways than landscape-level developments, which should enhance the transferability of the findings.

5.4 Recommendations for future research

In today's increasingly complex and fast-changing world, a long-term, visionary perspective is urgently needed in all sectors of society. This work focuses on understanding current and future influences in the operational environment of cadastral systems as well as on envisioning alternative futures for the Finnish cadastral system with the privilege of not having to consider any financial, technical or other type of constraint in the exploration. The introduction of some boundary conditions, i.e., prioritising certain social, economic or environmental objectives over others, would be needed if the goal were to take more concrete steps. This kind of action connects to the selection of a preferred future image in the futures studies literature, i.e., the fourth step of the integrated foresight process.

After the preferred future image is selected, strategies to realise the vision are needed. A shift to a strategy-oriented mindset would open many interesting research opportunities. First, the development of a strategic process in the context of land administration would deserve attention as the industry has specific features, such as the strong role of the public sector and the legal status of the content of cadastral systems, that distinguish it from many other contexts. Second, after the strategic goals have been set, a roadmap type of study would be in order because an understanding of the connections between the needed actions and the potential obstacles plays a critical role in realising the goals.

Then, in addition to the overall picture of the development of cadastral systems, more research is needed on the plethora of emerging issues identified in this dissertation. Even though this dissertation argues that it is unlikely that one individual innovation or technology will revolutionise the whole system, studies that aim to understand the economic, organisational, technical and legal implications of, for instance, new surveying technologies are needed. A lack of understanding on that front is likely to decelerate the development of the industry. In addition, the value aspect of providing 3D or 4D cadastral information requires more attention because calculating the direct monetary costs and benefits likely does not give a full picture of their feasibility.

Finally, to move away from the silo mentality of public data registers (in Finland and elsewhere), a coordinated effort to address the key issues and overlaps is needed. Organisational theories, for instance, could serve as a fruitful starting point for discussions about the interactions between different information systems.

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Cadastral system as the 'where' component of a property rights system is central to effective land markets, land use and sustainable development. Cadastral systems are dynamic by nature, as the historical evolution from fiscal and juridical cadastre to planning and multipurpose systems shows. This dissertation explores the future dynamism of mature cadastral systems, with a focus on the case of the Finnish cadastral system. It is concluded that the future of cadastral systems is a complex issue that cannot be reduced to individual technologies or innovations. Rather, this dissertation argues that more emphasis should be put on the institutional foundations, i.e., on the elements that coordinate and stabilize the established systems when the goal is to detect distinctively alternative configurations for cadastral systems. In addition to its academic value, this dissertation provides novel and fresh insights of future horizons of mature cadastral systems to actors of land administration domain.

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