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Design research for cadastral systems

Volkan Çağdaş [a,*], Erik Stubkjær [b,1]

[a] Yildiz Technical University, Department of Surveying Engineering, 34210 Istanbul, Turkey
[b] Aalborg University, Department of Development and Planning, 9220 Aalborg, Denmark

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ABSTRACT

Cadastral information is a reference data component, of any spatial data infrastructure (SDI). During recent years, several organisational and individual research projects have investigated the cadastral domain. Two paradigms characterize much of this research and their methodologies: a behavioural paradigm or, alternatively, a 'design research' paradigm. While some efforts have focused on behavioural research methodologies, design research methodologies have not been addressed by the cadastral, geographical information system (GIS) and SDI research community so far. The present article, therefore, aims to demonstrate usage of the design research paradigm through a methodological analysis of recent cadastral research, which addresses information system issues and within this context, designs information system artefact. The analysis is based on five doctoral dissertations and an array of papers representing the development of the ISO/WD 19152.3 Land Administration Domain Model. The analysis is supplemented with a review of related theory. The main contribution of this article is an explication of a design research methodology and a theoretical framework for research in cadastral information, cadastral systems and the units of property rights reflected in these systems.

1. Introduction

The purpose of this article is to introduce an emerging research paradigm, namely a 'design science' or 'design research' paradigm and its methodology to the cadastral, geographical information systems (GIS) and spatial data infrastructure (SDI) community. It also aims to present a set of theories and approaches relevant for cadastral research which may contribute to theory based, rigorous studies of the design of artefacts for cadastre, GIS and SDI.

The recording of cadastral information is a public affair which emerged before the era of computers, GISs and SDIs. Cadastral system is a commonly used term for recording cadastral information (cf. Dale & McLaughlin, 1999; Larsson, 1991) comprising of legal and spatial components. The legal component, land registration, refers to 'a process of official recording of rights in land through deeds or title' (Zevenbergen, 2002, p. 1). The spatial component, cadastre, means 'a systematic and official description of land parcels, which includes for each parcel a unique identifier'. The description includes text records on attributes of each parcel. The prototypical means of identification is a large-scale map that provides information on parcel boundaries (Silva & Stubkjær, 2002, p. 410).

Over the course of nearly three decades, researchers have focused on several aspects of cadastral systems. This work may be broadly classified according to its theme as addressing: (i) social science aspects, or (ii) information science aspects (Çağdaş & Stubkjær, 2009, p. 870). Research focusing on social science aspects primarily studies the recording of real property rights and land tenure from, e.g. anthropological, economical, geographical, historical, legal, organisational, and political point of views. Searching for common methodological and conceptual elements, Çağdaş and Stubkjær (2009) analyzed 10 dissertations which were written in English language, defended recently, and available on the World Wide Web. Although their themes varied, they all addressed: (1) rights in land and (2) the official recording of these rights through national information systems. The present research focuses on the information science aspect which occurs at the confluence of people, organisations and technology; therefore, two distinct and complementary paradigms are necessary to acquire the knowledge required to improve information systems (IS): a *behavioural research* and a *design science* or *design research* paradigm (Hevner, March, Park, & Ram, 2004, p. 79). Briefly, the behavioural research paradigm is primarily focused on the understanding and justification of human–computer-interaction, specifically to identify organisational problems, while the design research paradigm seeks to create information technology artefacts intended to solve such problems (Becker et al., 2007, p. 130).

Design research is a relatively new paradigm which has enjoyed a growing interest by the IS research community (e.g. Gregor,

* Corresponding author. Tel.: +90 212 383 5313; fax: +90 212 383 5102.
E-mail addresses: volkan@yildiz.edu.tr (V. Çağdaş), est@land.aau.dk (E. Stubkjær).
[1] Tel.: +45 99 40 83 50; fax: +45 98 15 65 41.

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2006; Hevner et al., 2004; Kuechler & Vaishnavi, 2008; Livari, 2007; March & Smith, 1995; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2008; Venable, 2006; Winter, 2008). Conversely, the majority of studies which address aspects of cadastral systems have applied the behavioural research paradigm, and with a scope that often extends beyond the boundary of information systems. Some research on cadastre and SDI may in fact be classified under the design research paradigm, even if this is not stated explicitly in the research concerned, i.e. Bittner (2001), Effenberg (2001), Bittner and Frank (2002), van Oosterom and Lemmen (2002), Billen and Zlatanova (2003), Stoter and Salzmann (2003), Tse and Gold (2003), Navratil and Frank (2004, 2007), Stoter (2004), Tuladhar (2004), and van Oosterom et al. (2006).

This situation is, however, not very different from the IS field, as Peffers et al. (2008) note that the design research paradigm was only occasionally used explicitly in IS field, even if a sufficient conceptual and paradigmatic basis was available in the early 1990s (p. 48). We join with Peffers et al. in order to contribute to a more rigorous studies of the design of artefacts for cadastre and SDI. For that reason, in Section 2, a brief introduction to design research paradigm is presented (Section 2.1), then the *design research methodology* proposed by Peffers et al. (2008) is introduced (Section 2.2). The design research methodology is then used as a guide for analysing recent research on the information science aspects of cadastral systems (Section 3).

The design research methodology implies that the development of the artefact draws on existing theories and knowledge (cf. Peffers et al. (2008), p. 49, quoting Hevner et al. (2004)). Cadastre as a core component of national GISs and SDI is embedded in public administration. In fact, there is a general agreement that in order to manage cadastre, land administration, and SDI, a number of, legal, organisational, and other social science aspects have to be taken into consideration, i.e. Martin (2000), Harvey (2001), Williamson (2002), Comber, Fisher, and Wadsworth (2003), Georgiadou, Puri, and Sahay (2005, 2006), Karikari, Stillwell, and Carver (2005), De Man (2006), Stubkjær (2006), Omran and van Etten (2007), Grus, Crompvoets, and Bregt (2010). Accordingly, the development of cadastre, GIS and SDI needs a theoretical basis covering technical and social disciplines in an integrated manner. However, the lack of clear theoretical bases in the reviewed research (cf. Section 3.4) prompted us to review theories and approaches applied in cadastral research, including (general) systems theory, actor-network theory, and new institutional economics (Section 4). Drawing on these reviews we, in Section 5, propose a coherent framework which may develop into a paradigm for cadastral design research. The last section presents conclusions of the article.

2. The design research paradigm and its methodology

This section introduces the design research paradigm (Section 2.1), and presents its methodology (Section 2.2). The main purpose is to inform the cadastral and SDI community of an emerging research paradigm and its methodology which may contribute to more rigorous design research studies.

2.1. Characteristics of the design research paradigm

In recent years, several individual and organisational research projects have been performed within the cadastral domain. An analysis of this research allows for the identification of different research patterns or paradigms. By *paradigm* we refer to the theoretical and methodological traditions which provide the researcher with an intellectual context for conducting research (cf. Blaikie (2000), p. 9, referring to Kuhn (1970)). In the original conception by Thomas Kuhn, these traditions are materialized in textbooks and courses that socialize students and practitioners into the concerned scientific communities (cf. Frankfort-Nachmias & Nachmias (1997), p. 17, referring to Kuhn (1970)). In the present context, the traditions are emergent (cf. Section 2) and anticipated (cf. Sections 2 and 5).

The behavioural science paradigm seeks to develop and verify theories that understand or predict humans and organisational behaviour (Hevner et al., 2004, p. 77). Such research aims at understanding reality by developing a set of concepts which are used in higher order constructions – laws, models, and theories (March & Smith, 1995, p. 253). On the other hand, the design research paradigm seeks to create and evaluate an artefact intended to solve identified organisational problems within the IS field (Hevner et al., 2004, p. 77). In a nutshell, the behavioural research paradigm stresses 'what is reality' while the design research paradigm stresses the 'utility of IS artefact' (Carlsson, 2006, p. 194).

According to Carlsson (2006), the aim of design research is to develop practical knowledge for the design and realization of 'information system initiatives', or to be used to improve the performance of existing IS (p. 198). Design research comprises a rigorous process to design artefact to solve observed problems, to evaluate designs, and to communicate results to appropriate audiences. The objective is to 'create things that serve human purposes'. Such artefact are broadly defined as *constructs*, *models*, *methods*, and *instantiations* (March & Smith, 1995, p. 253) and are created to enable the representation, analysis, understanding, and development of successful IS within organisations (March & Storey, 2008, p. 726). They may also include social innovations or new properties of technical, social, or informational resources; in short, this definition includes any designed object with an embedded solution to an identified research problem (Peffers et al., 2008, p. 49). Furthermore, the notion of artefact is qualified as more likely to be an idea, practice or partial product than a ready-for-business-use IS (Hevner et al., 2004, p. 83).

In order to utilize this paradigm, Peffers et al. (2008) proposed a methodology for the production and presentation of design research in IS. Basically, this methodology may be seen as a guideline for effective design research. It aims to provide a commonly accepted framework for carrying out design research and a mental model for its presentation. It may also help with the recognition and legitimization of design research and its objectives, processes, and outputs, and it should help researchers to present research with reference to a commonly understood framework, rather than justifying the research paradigm on an ad hoc basis with each new paper (p. 48). The next section briefly presents the design research methodology developed by Peffers et al. (2008).

2.2. Design research methodology

A *scientific methodology* may be defined as a system of explicit rules and procedures upon which research is based and against which claims for knowledge are evaluated (Frankfort-Nachmias & Nachmias, 1997, p. 13). Peffers et al. (2008)'s design research methodology consists of the following six steps:

(i) Problem identification and motivation.
(ii) Definition of the objectives for a solution.
(iii) Design and development.
(iv) Demonstration.
(v) Evaluation.
(vi) Communication.

In the *first step* of the research, a specific research problem should be defined and the value of a solution should be justified. Therefore, the research has to demonstrate knowledge of the current state of the art and the relevance of the identified problem.

The *second step* infers the objectives of a solution from the problem definition and knowledge of what is possible and feasible. In the *third step*, artefacts are created. Such artefact are potentially concept-constructs, models, methods, instantiations or new properties of technical, social, and/or information resources. The *fourth step* of the methodology demonstrates the use of the artefact to solve the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity. The *fifth step*, namely, evaluation, observes and measures how well the artefact supports a solution to the problem. This activity involves comparing the objectives of a solution to results observed through the use of the artefact in the methodological demonstration. It requires knowledge of relevant metrics and analysis techniques. The *last step*, communication, refers to dissemination of the new knowledge obtained by the research in terms of, i.e. dissertations or journal articles (Peffers et al., 2008, pp. 52–56). In the following section, methodological aspects of the selected research were analyzed according to these guidelines.

3. Review of recent research on the information sciences aspect of cadastral systems

During the last decade, a number of analysis and review studies focusing on cadastral and GIS literature were published. For instance, Silva and Stubkjær (2002) reviewed nine journal articles focusing on the institutional, social, political and economic aspects of cadastral development. Their purpose was to contribute to the acceptance of research methodologies needed for cadastral development, and thereby enhance theory in the cadastral domain (p. 403). Later, Akingbade, Navarra, and Georgiadou (2009) presented a review the literature on the impacts of GIS in governmental and non-governmental organisations by analysing 53 journal articles published between 1998 and 2008. The authors suggested that appropriate use of theories, concepts and testing of existing GIS evaluation frameworks could serve for more rigorous studies on the impact of GIS (p. 84). More recently, similar to the present study, Çağdaş and Stubkjær (2009) analyzed doctoral dissertations according to a behavioural research paradigm, stressing the social science aspects of the cadastral domain. It demonstrated the methodological and theoretical aspects of the selected dissertations and presented a taxonomy for further research (p. 869). Finally, Roux and Barry (2009) emphasised the importance of research paradigms by evaluating the usefulness of postpositive, social construction, advocacy and pragmatic paradigms in the cadastral field.

Here we continue these prior efforts by reviewing recent research which focus on the information science aspect of cadastral systems and which inherently applies the design research paradigm outlined in Section 2.2. For this purpose, the following doctoral dissertations and publications representing advancements of the ISO/WD 19152.3 LADM, were selected which address information sciences aspect of the cadastral domain, present several IS artefact:

- *An agent-based model of reality in a cadastre* by Bittner (2001) at Technical University Vienna (Supervisor: Univ.-Prof. Dr. A. Frank).
- *Spatial Cadastral Information Systems – the maintenance of digital cadastral maps* by Effenberg (2001) at University of Melbourne (Supervisor: Prof. Dr. I. Williamson).
- *3D Cadastre* by Stoter (2004) at Delft University of Technology (Supervisors: Prof. Dr. Ir. P.J.M. van Oosterom and Prof. Dr. J. de Jong).
- *Parcel-based geo-information system: concepts and guidelines* by Tuladhar (2004) at International Institute for Geo-Information Science and Earth Observation (Supervisors: Prof. Dr. Ir. M.J.M. Bogaerts and Prof. Ir. P. van der Molen).
- *Developing geographic information infrastructures – the role of information policies* by van Loenen (2006) at Delft University of Technology (Supervisors: Prof. Dr. J. de Jong and Dr. Ir. J.A. Zevenbergen).
- *ISO/WD 19152.3 Land Administration Domain Model* (earlier called Core Cadastral Domain Model) (ISO/TC211, 2008; Lemmen & van Oosterom, 2006; Lemmen, van Oosterom, Uitermark, Thompson, & Hespanha, 2009; van Oosterom & Lemmen, 2002; van Oosterom et al., 2006).

The selected research designed several *models* and instantiated them for evaluating or improving components of the cadastral systems, GISs and SDIs. While some of these models serve the business community by applying technological innovations to improve the effectiveness of an organisation and its services, the others serve the academic community by bringing new visions to better understand a phenomenon. Therefore, we distinguished three of the dissertations, Effenberg (2001), Stoter (2004), Tuladhar (2004) and the ISO/WD 19152.3 LADM as addressing the efficiency and effectiveness of 'real world' cadastral systems, from Bittner (2001) and van Loenen (2006) which design models for use in 'academic world' research on cadastral systems and SDIs. We also considered

- *Formalisierung von Gesetzen – Am Beispiel des Österreichischen Allgemeinen Grundbuchsgesetzes* by Navratil (2002) at Technische Universität Wien. (Supervisor: Prof. A. Frank)

for inclusion, but decided to only mention it as representative of academic work performed in other languages than English. In the following sub-sections, methodological aspects of the selected research were analyzed according to the guidelines proposed by Peffers et al. (2008) in the context of *design research methodology*, as previously introduced. This analysis provides an account of the problem identification and the objectives of the selected research (Section 3.1), designed models (Section 3.2), demonstration, evaluation and communication of designed models (Section 3.3), and applied theories (Section 3.4).

3.1. Problem identification and definition of the objectives

As described in Section 2.2, problem identification and definition of objectives constitute the first and second steps of design research methodology, respectively. Basically, in the first step, a specific research problem should be identified and the value of a solution should be justified. Then, in the second step, the objectives of a solution should be demonstrated from the problem definition (Peffers et al., 2008, pp. 52–56).

As illustrated in Table 1, all reviewed research includes a well defined research problem and objectives for the proposed solution. Among the first group of dissertations, Effenberg (2001) and Stoter (2004) studied aspects of cadastral maps and cadastral registers. While the former investigated possibilities to register three dimensional (3D) rights to cadastral maps and registers, the later focused on models for maintaining cadastral maps. The research carried out by Stoter (2004) was motivated by the fact that land use, especially in urban areas, is becoming increasingly complex due to technical infrastructure both above and under ground. While traditional land registration may still be sufficient to register rights in land, present cadastral maps and registers are unable to represent spatially complex real property rights precisely. Therefore, Stoter researched the needs, constraints and possibilities for 3D cadastral registration (2004, p. 7). The dissertation by Effenberg (2001) focused on the maintenance and distribution of cadastral maps. In order to ensure efficient public services, cadastral maps must be kept updated, have high spatial accuracy and be distributed efficiently between

Table 1
Defined research problems (Step 1) and objectives of solutions (Step 2).

Research	Research problem	Objectives of solution	Cases	Data collection techniques
Bittner (2001)	Understanding reality in a cadastre from an institutional point of view	To construct a computational model in order to simulate social processes in a cadastre	Austria	Literature review
Effenberg (2001)	Maintaining cadastral maps from a technical point of view	To design a conceptual model for effective, efficient and timely maintenance and distribution of cadastral data in a digital environment	Victoria and New South Wales (Australia)	Literature review Unstructured interviews
Stoter (2004)	Improving 3D cadastral registration from a technical point of view	To design data models based on current registration and available techniques in order to improve 3D cadastral registration	Netherlands, Denmark, Norway, Sweden, Queensland (Australia), British Columbia (Canada), Israel	Literature review
Tuladhar (2004)	Developing cadastral system in Nepal and Bhutan from a technical point of view	To design a system models for a parcel-based GIS which supports the administration of land and meets needs of the society	Nepal and Bhutan	Unstructured interviews
van Loenen (2006)	Understanding development of a GII from an organizational-stakeholder point of view	To design a model that describes the stages of development of information infrastructure, and their dynamics	Netherlands, Denmark, North Rhine Westphalia (Germany), Massachusetts and Minneapolis – St. Paul (USA)	Literature review Semi structured interviews
ISO/WD 19152.3 LADM	Enabling effective communication between land administration systems from a technical point of view	To design a reference domain model based on the conceptual framework of Cadastre 2014 and available international geo-spatial standards	–	Literature review Views of domain experts

the governmental organisations. Noting the potentials of digitized maps and web enabled services, Effenberg applied an IS approach to achieve effective, efficient and timely maintenance and distribution of the cadastral data in the cases of Victoria and New South Wales (Australia) (2001, pp. 4–5). Similarly, the dissertation by Tuladhar (2004) focused on the IS aspect of cadastral systems in the cases of Nepal and Bhutan. After determining that existing methods for the acquisition, storage, maintenance, and dissemination of data were inadequate, the work sought to develop system models for a parcel-based GIS supporting the administration of land.

The second group of dissertations consisting of Bittner (2001) and van Loenen (2006) address basic, ontological aspects and thereby bring new visions to the understanding of the nature of a cadastre and of a SDI, respectively. According to Bittner (2001), most models of the cadastre describe the cadastre as a database and discuss its internal formal rules. However, it is not possible to discuss all relevant aspects of cadastral processes by investigating its input and output operations (p. 56), as these processes capture only a part of the reality. Hence, it is necessary to widen the scope to a more general view of 'reality in a cadastre' (p. 13). Through his research, Bittner specified a simulation model that represents the cadastral registry embedded in its environment in order to analyze cadastral reality (2001, p. 14). The final dissertation presented by van Loenen (2006), investigated the dynamics of development of the SDI or geographical information infrastructure (GII). The motivation of his research was the unavailability of a general model to explain the development of a GII leading him to develop a model describing the various stages of GII development from the organisational and data characteristics point of views (pp. 6–11).

The last research, ISO/WD 19152.3 LADM, was motivated by a requirement for international standardization and harmonization of cadastral systems. As van Oosterom et al. (2006) pointed out, in existing cadastral systems, standardization is limited to the territory or jurisdiction where the cadastral system is in operation. However, open markets, globalisation, and effective and efficient development and maintenance of flexible (generic) systems ask for further standardization (p. 629). Therefore, ISO/WD 19152.3 LADM aims to achieve two main goals: (i) to provide an extensible basis for efficient and effective cadastral system development based on a model driven architecture and (ii) to enable multiple involved parties, both within and between countries, to communicate based on the shared ontology implied by the model (ISO/TC211, 2008, p. 7).

3.2. Design and development

In the third step of the presented methodology, artefacts are designed. These artefacts could be concept or constructs, models, methods or instantiations. The *constructs* or *concepts* form the vocabulary of a domain, constituting a conceptualization used to describe problems within the domain and to specify their solutions. The next type of artefact, the *model,* is a set of propositions or statements expressing relationships among constructs. A *method* is a set of steps (an algorithm or guideline) used to perform a task. Methods are based on a set of underlying constructs. The last type of artefact, the *instantiation,* is the realization of an artefact within its environment. It demonstrates the effectiveness of the models and methods they contain (March & Smith, 1995, pp. 256–258).

All of the reviewed research included the development of models, as summarized in Table 2, signifying their utility in this field. Effenberg (2001) provided *a conceptual cadastral update model* for the selected cases, applying the Zachman Framework as a methodology for defining and structuring alternative maintenance models for the spatial cadastral sub-system. The dissertation by Tuladhar (2004) presented organisational, static and dynamic models for

Table 2
Designed models in the reviewed research, and demonstration of their utility.

Research	Designed model	Modelling language	Utility demonstration
Bittner (2001)	A computational agent-based model of reality in a cadastre	Haskell functional programming language	Computational model was simulated by agent-based approach for selected two cases from the Austria Cadastre
Effenberg (2001)	A conceptual cadastral update model	–	–
Stoter (2004)	Conceptual and logical models for a 3D Cadastre	UML (class diagram)	Conceptual models were translated to logical models and implemented prototypes in case studies from Netherlands and Queensland – Australia
Tuladhar (2004)	Organizational, static and dynamic models for a parcel-based GIS	UML (use case, activity, state, component and class diagrams)	Some business services within the cadastral surveying sub-system were prototyped in the case of Nepal
van Loenen (2006)	GII maturity matrix and framework dataset maturity matrix	–	Case study methodology was applied to demonstrate utility of the designed models in the cases of the Netherlands, Denmark, North Rhine Westphalia-Germany, Massachusetts – USA, and Minneapolis – St. Paul – USA
ISO/WD 19152.3 LADM	A reference domain model for land administration systems	UML (class diagram)	Formal consensus process

the parcel-based GIS in the selected cases by using UML diagrams. The last dissertation within this group, Stoter (2004), developed three *conceptual data models for 3D Cadastre* by UML class diagrams: (1) full 3D cadastre, (2) hybrid cadastre, and (3) 3D tags linked to parcels in current cadastral registration.

Within the second group of dissertations, van Loenen (2006) developed *a GII maturity matrix* for describing the stages of GII development and *a framework dataset maturity matrix* for identifying levels of dataset qualities related to GII development. While the GII maturity matrix identifies development stages of the GII based on several organisational components, the framework dataset maturity matrix determines development stages of the cadastral and topographical dataset. The second dissertation in this group, Bittner (2001), developed *a computational model to represent reality in a cadastre* through an agent-based conceptualization approach and the Haskell functional programming language. His model is based on *ontology of institutional reality* which is an application of Searle's theory of social reality.

The last research, ISO/WD 19152.3 LADM created *a reference domain model for land administration systems* in terms of UML class diagrams based on the conceptual framework of the Cadastre 2014, ISO and OpenGIS standards (ISO/TC211, 2008, p. 7; van Oosterom et al., 2006, p. 627). Its first version, called Core Cadastral Domain Model (CCDM), was proposed by van Oosterom and Lemmen (2002). Based on the outcome of an array of collaborative efforts, the *Version 1.0 of the FIG Core Cadastral Domain Model* was presented (cf. Lemmen & van Oosterom, 2006). In 2008, CCDM was renamed as LADM, and submitted as a new working proposal to the ISO by FIG (Lemmen et al., 2009). The ISO/WD 19152.3 LADM provides an abstract, conceptual schema with five basic packages related to: (1) parties (people and organisations); (2) spatial units (parcels); (3) rights, responsibilities, and restrictions (property rights); (4) spatial sources (surveying); and (5) spatial representations (geometry and topology) (ISO/TC211, 2008, p. 1).

3.3. Demonstration, evaluation and communication

According to Peffers et al. (2008), the fourth and fifth steps of the research should demonstrate the use of the model to solve the identified problem, and measure how well the model solves the problem, respectively. These steps also may be viewed as a *validation* of the research findings. In the reviewed research, the utility of the developed models was evaluated via simulation, case studies or prototypes (cf. Table 2 below).

Stoter (2004) developed three logical models from the conceptual models through object relational modelling, and implemented them with Oracle Spatial software to selected cases (p. 251). Based on the results of the prototype implementations, the researcher asserted that a full 3D cadastre offers the best potential compared to traditional cadastres and is realisable in countries where volume parcels are established within the juridical framework (p. 296). Tuladhar (2004) demonstrated some business services through prototype implementation. Three business processes: initial data loading/structuring, subdividing parcels and transfer of ownership were prototyped by Oracle 9i Designer 2000 software (p. 148). In this exercise, the business processes were analyzed to assess needed resources (personal, cost and time) of responsible organisational units. Given the resource estimates, the success of services was assessed to be dependent on co-operation, coordination and financial arrangement of the responsible departments (p. 172). Bittner (2001) applied an agent-based simulation approach to demonstrate the utility of his model of reality. He simulated two processes of the Austrian Cadastre, namely, the transfer of ownership of a parcel, and conflicts on land use and their resolution. The computational agent-based model was found to correctly and successfully represent the stated reality in a cadastre (p. 135). Finally, van Loenen (2006) used case study methodology to demonstrate the utility of his models. The developed matrices were evaluated as a first attempt to model GII development (p. 301). Evaluation of the ISO/WD 19152.3 LADM takes place through a six step consensus process (http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm), which eventually results in a published standard.

The last step of the methodology, communication, was already accomplished by the doctoral dissertations themselves, as well as by a number of conferences, workshop papers, and journals articles concerning the development of the ISO/WD 19152.3 LADM.

3.4. Applied theories

As revealed by the review, the research includes only few statements and explanations regarding the applied theories and their content, except for Bittner (2001). For instance, Effenberg (2001) and Tuladhar (2004) built their research according to principles of systems theory, but they did not make explicit statements regarding this theory. Similarly, Stoter (2004) and van Loenen (2006) mention a 'spatial data modelling theory' (pp. 99–120) and a 'geographical information infrastructure theory' (p. 17), but they did not explain content of these theories, as demonstrated in Table 3 below.

Bittner (2001) presented and based his model on Searle's theory of social reality. In short, Searle's social reality theory explains how *institutional reality* (e.g. money) is constructed and relates to *physical reality* (e.g. paper). The concepts of social reality theory include physical and institutional facts, status functions, collective intentionality, constitutive rules and conventional power assigned to

Table 3
Application of theories in the reviewed research.

Research	Applied theories	
	Explicit application	General reference
Bittner (2001)	Searle's social reality theory Multi-agent theory	–
Effenberg (2001)	Zachman framework	System development methodologies
Stoter (2004)	Object oriented modelling	Spatial data modelling theory
Tuladhar (2004)	Object oriented modelling	System modelling approaches
van Loenen (2006)	–	Geographical information infrastructure theory
ISO/WD 19152.3 LADM	Object oriented modelling	–

institutional facts. *Physical facts* exist within physical reality and, similarly, Searle asserts that *institutional facts* exist within institutional reality. According to Searle, institutional facts are characterized by the assignment of some *status* to physical phenomena by collective intentionality, meaning the human capability to collectively share intentional states, such as beliefs and intentions. The rules, which enable the imposition of a status function, are called *constitutive rules* and can be codified by, i.e. statutory (cadastral) law. *Conventional power* is assigned to institutional facts, i.e. rights and duties (Bittner, 2001, pp. 35–42).

Concluding this section, evidence was provided that all reviewed research presented applications of the design research paradigm by designing several artefacts and instantiating them for evaluating or improving cadastral systems and SDIs. However, despite their fruitful contributions, none of the reviewed research explicitly referred to a design research paradigm. Therefore, the methodological framework introduced presents a basis for more rigorous design studies for cadastre and SDI. Moreover, the scattered theoretical bases in the reviewed research prompted us to refer to theoretical underpinnings of cadastral research. The following section, thus, documents applied theories and discuss their usefulness.

4. Theories applied in cadastral research

A *theory* is a deep, principled explanation of phenomena (March & Smith, 1995, p. 253). Theories aim to describe, explain, and enhance understanding of the world and, in some cases, to provide predictions of what will happen in the future and to give a basis for intervention and action (Gregor, 2006, p. 616). As Gregor (2002) observes, in the IS field many researchers who use the word 'theory' in their work fail to give any explicit definition of their own view of theory (p. 1). This statement was also validated by our review presented in Section 3.4.

Literature on cadastre presents applications of a number of theories and theoretical approaches developed within natural, social and behavioural sciences. These theories and their power could be evaluated in a number of ways. For instance, Gregor (2002, 2006) developed a taxonomy and then evaluated theories applied in IS research based on this taxonomy.

Gregor's taxonomy classifies theories based on their goals as follow: (i) theory for analysing, (ii) theory for explaining, (iii) theory for predicting, (iv) theory for explaining and predicting, and (v) theory for design and action. According to Gregor, *analytic theories* analyze 'what is' as opposed to explaining causality or attempting predictive generalizations. Within this type, specific dimensions or characteristics of individuals, groups, situations, or events are described or classified by summarizing commonalities found in discrete observations (2006, p. 622). The second type, *theory for explaining*, focuses on how and why some phenomena occur. These theories are formulated in such a way, however, that making testable predictions about the future is not of primary concern. Explanations of how, when, where, and why events occurred may be presented, giving rise to process-type theory (2006, p. 624). The third and fourth type of theory, *theory for prediction* and *theory for explaining and predicting* are not sufficiently relevant to be detailed here. The last type of theory, *theory for design and action* says how to do something. It is about the principles of form and function, methods, and justificatory theoretical knowledge that are used in the development of IS (2006, p. 628).

Based on Gregor (2002, 2006)s taxonomy, the following subsections present and discuss main theories and approaches applied in cadastral research, including (general) systems theory, actor-network theory, new institutional economics, and stakeholder and social network analysis. Finally, in Section 5, an attempt is made in order to consolidate these theories into a coherent set.

4.1. Systems theory

Systems theory was founded by scientists including the biologist Ludwig von Bertalanffy and the psychiatrist William Ross Ashby in the last century (Navratil, Twaroch, & Frank, 2005, p. 159). It aims at seeking principles common to systems in general that may allow scientists and researchers to think more clearly about the goals of any possible system, and about the methods for achieving them (cf. Von Bertalanffy, 1969). Among the theories used in cadastral research, systems theory fits the types of *theory for analysing*, and *theory for explaining* (types I and II) by enabling the description and analysis of a group of entities which comprises a whole and produces some results. The theory provides for a taxonomy which allows for explaining observed phenomena in terms of a system (Çağdaş & Stubkjær, 2009, p. 879), and – depending on the research design – for explaining its outcomes. Remarkably, systems theory has been applied to the cadastral domain for a long time by, e.g. Dale (1979), Nichols (1993), and Zevenbergen (2002). Dale (1979), for instance, presented a systems view of the cadastre by a conceptual model incorporating aspects (legal, fiscal and multipurpose), elements (land, law, people), and external factors (technology, history and education) of the cadastre. Similarly, Nichols (1993) depicted a system model for land registration consisting of the following four perspectives: the technology perspective, the cadastral perspective, the land policy perspective, and the conveyancing perspective. Later, also Zevenbergen (2002) approached land registration from a systems thinking point of view and focused on its aspects: primarily technical, legal, and organisational, but also socio-cultural and financial–economical.

Systems theory provides a framework for researchers, i.e. systems thinking, which emphasises the idea that a particular problem or phenomenon should be defined in terms of an irreducible whole. The elements of this whole may be analyzed individually, but basically, it is the whole that should be the focus of analysis. In sum, this is an approach to a problem which takes a broad view, which tries to take all aspects into account, and which concentrates on interactions between the different parts of the problem (Checkland, 1999, p. 5).

A systems thinking approach may exhibit two different types of approaches: 'hard systems thinking' and 'soft systems thinking' (cf. Checkland & Scholes, 1990). While the former originated in engineering to generate solutions to technical problems, the latter emerged when modelling complex human activity processes (Nidumolu, de Bie, van Keulen, Skidmore, & Harmsen, 2006, p. 189). Furthermore, a Socio-Technical Systems approach provides a different insight into engineering systems, where the social and technical elements are strongly interconnected. The following subsections provide a review of these approaches.

4.1.1. Hard systems thinking

'Hard systems thinking' in the context of this article corresponds the type of *theory for design and action* (type V). It implies that the world consists of systems that can be 'engineered' to achieve stated objectives. To solve a perceived problem in the hard systems approach is to 'engineer' improvements in the real-world systems by discovering optimal solutions for it (Checkland & Holwell, 1998; Nkwae, 2006, p. 37). It uses causal logic and focuses on natural or designed systems (Röling, 1997, p. 253). In hard systems thinking, the problem, system boundaries and expected outcomes can be defined precisely, and optimum designs can be produced with scientific engineering approaches within a project cycle. System boundaries are established in such a way that human behaviour and social and institutional factors are excluded, or they are covered in a simplified manner. Therefore, hard systems thinking is appropriate in situations where people concerned agree on the definition of problems and goals of design (e.g. software or hardware design).

From the hard systems point of view, a cadastral system may be considered strictly an information or record keeping system (Cashin & McGrath, 2006, p. 631). Undoubtedly, surveying, mapping and technologies for dissemination of geospatial information, i.e. technical elements, are necessary for defining real property units and maintaining rights thereon. Therefore, cadastral procedures or a parcel-based GIS might be designed according to a hard system thinking approach. However, the establishment and maintenance of such systems does not only involve technical processes, but also political–economic, cultural (Sikor, 2006), legal and administrative aspects. Hence, the legal and social rules, summarized as social elements, do not fit the hard systems thinking. As Nkwae (2006) states, the reason why hard systems thinking fails in the design of land administration systems is that it ignores the socio-cultural aspects of a problem situation (p. 72).

4.1.2. Soft systems thinking

Another approach within systems thinking, soft systems thinking, was developed for overcoming the previously-mentioned shortages of hard systems thinking. Similarly, soft systems thinking could be classified under the heading of *theory for design and action* (type V) (cf. Gregor, 2002, p. 12), as it enables design and action for solving unstructured problems within the area of human activity systems. However, contrary to the hard systems thinking, soft systems thinking assumes that the definitions of problem and of system objectives must include the different perceptions of the people who are involved in or affected by the system.Therefore, soft systems methodology direct the researcher to engage people in discussion and debate with the purpose of accommodating for their different perspectives and reaching some sort of consensus regarding the problem situation and possible solution (Dahlbom & Mathiassen, 1993; Nkwae, 2006, p. 58). A methodology for soft systems thinking, i.e. the soft systems methodology (SSM), was developed by Checkland (1981) and defined by Checkland and Scholes (1990) as 'an organised way of tackling messy situations in the real world (p. 1); it is based on systems thinking, which enables it to be highly defined and structured, but remain flexible in use and broad in scope. SSM proposes a recursive methodology in order to develop a design consistent with the environment of the system.

SSM was applied to the cadastral field by Stubkjær (2000) while establishing a theoretical basis for cadastral studies. Then, Barry and Fourie (2002) used soft system thinking for analysing the interrelationship between cadastral and land management subsystems of South Africa. They proposed a conceptual model which reflected South Africa's unstable conditions with no definite hierarchy between land management sub-systems, and in which the definition of problems and objectives was relatively complex. Later, Augustinus and Barry (2006) pointed out how soft systems thinking makes it possible to move away from the conventional simplistic, hard interventionist sub-system focused design exercises. Similarly, SSM provided a framework for Rakai (2005) and Nkwae (2006) in their analysis of land tenure and land administration problems.

Soft system thinking has several advantages as it encourages an iterative process of viewing the situation from a number of different viewpoints or perspectives. Moreover, it enables a collaborative approach to establishing a debate about possible improvements to complex problems. In summary, it considers human behaviour and the parties' various perspectives, and also accommodates for a system environment that includes social, cultural, and economic elements. Therefore, in a design or implementation project regarding cadastre, GIS or SDI, soft system thinking supports project management.

4.1.3. Socio-Technical Systems

In addition to hard and soft systems thinking, mention is made of an ongoing research project, headed by the Delft University of Technology called 'Modelling Infrastructures as Socio-Technical Systems'. The project framed development of an approach for analysing Socio-Technical Systems (STS), which is defined by Kroes, Franssen, Poel, and Ottens (2006), as engineering systems that need actors and some social/institutional infrastructure to be in place in order to perform their function (p. 804). In accordance with this approach, STS comprises three categories of elements: technical elements, actors, and social elements. The first category, *technical elements*, includes non-intentional elements and is subject to the laws of nature. Next, the category of *actors* consist of physical persons as well as legal persons, such as organisations of any kind, and finally, groups. What is decisive is that actors possess intentionality. Although intentionality is directly linked to the mind of a person, groups and organisations may act with a shared intentionality. Thus, organisations and organisational units may be considered as sub-categories of the actor element. The last category is *social elements*. Formal rules like statutory acts and informal rules, i.e. personal ethics, are good examples of a social element. Social elements tend to restrict the behaviour of actors in analogy with technical elements being dependent on the laws of nature (cf. Kroes et al., 2006).

While hard and soft system thinking approaches enable design and action, the STS approach provides an explanation of system elements and their nature and dynamics classifying it as a *theory for explaining* (type II). The STS approach was first applied to cadastral systems by Ottens (2004), and subsequently Stubkjaer (2006) and Ottens and Stubkjær (2007) continued this effort and described cadastre as a STS. In summary, the STS view of the cadastre, facilitates a more rigorous explanation for the domain by separating and treating actors, social and technical elements in different ways. This rigorous explanation may be achieved by applying appropriate disciplines to each of the categories: engineering to technical elements, organisational studies to actors, and law and political science to the social elements.

4.2. Actor-network theory

The literature shows different interpretations of the interplay between people and technology, especially in organisational studies, which focus on joint optimization of people and technology in organisations. One of the early research traditions is actor-network theory (ANT) which was developed from Michel Callon and Bruno Latour's previous studies, i.e. Callon (1986), Latour (1987), and recently Boudourides (2001). ANT was developed in order to understand how entrepreneurs build networks combining technical, social and economic elements, in order to reflect that these elements are both constituted and formed in these networks. An actor-network is built of both technical and non-technical elements to form a heterogeneous network, which among others implies that ANT grants both humans and non-humans the same explanatory status (Ljungberg, 2008, p. 9).

ANT was introduced to the GIS and SDI community by Martin (1998). Martin (2000) later examined actors and their interactions within a GIS implementation project in Ecuador; and Comber et al. (2003) applied a similar approach for comparing actors and their networks in two different land cover mapping projects. Recently, De Man (2006) pointed out that the process of developing networked assemblies for SDI is viewed by ANT as interplay between heterogeneous actors: technological and social elements tied together in actor networks (p. 333).

In essence, ANT offers IS research a language for describing how technical and non-technical elements can form a network of actors that will negotiate interests and try to gain influence (Ljungberg, 2008, p. 8). Thus, it corresponds to the *theory for explaining* (type II) within the previously mentioned taxonomy (cf. Gregor, 2002, p. 8). In summary, ANT could be used for explaining the interrelationship between actors within a cadastral or SDI design project. Although non-human actors cannot have intentionality by themselves, this theory assumes that intentional and unintentional elements have the same effect on change.

4.3. Institutional economics

New institutional economics (NIE) is an interdisciplinary enterprise combining economics, law, organisational theory, political science, sociology and anthropology in order to understand the institutions of social, political and commercial life. Its goal is to explain what institutions are, how they arise, what purposes they serve, how they change and how – if at all – they should be reformed (ISNIE, 2009).

This theoretical approach provides a base for understanding the role of institutions and organisations in the process of, for instance, development of cadastre. In economic terms, it focuses on the mutual interrelationship between organisations and institutions for economic development. The notion of 'institutions' has in institutional economics another meaning than the common notion of financial or social institutions. The concept of *organisation* refers to groups of individuals who cooperate or act jointly for some common purpose to achieve stated objectives (North, 1990, p. 5). Thus, institutional economics conceptualizes financial or social institutions as organisations. Organisations tend to reduce transaction costs in order to increase their economic efficiency; consequently, these activities result in the emerging or transforming of institutions. Institutions emerge and evolve in a society to reduce uncertainty by providing a structure to everyday life. North (1990) defines *institutions* as the rules of the game in a society or, more formally, [they] are the humanly devised constraints that shape human interaction (p. 3). Institutions become visible in terms of legislation and ordinances, articles and rules, written codes of conduct, etc., but the concept also includes tacit norms which are transferred through education and socialisation. Thus, they have both a formal and an informal aspect. Together with the technology employed, institutions determine the transaction and transformation (production) costs that make up total costs (North, 1990, p. 28). The term *transaction costs* denotes a large variety of costs involved in a transaction; the cost consists of measuring the valuable attributes of what is being exchanged, as well as the costs of protecting rights and policing and enforcing agreements (North, 1990, p. 27).

NIE was introduced to the FIG community, for example by Hans Sevatdal (1999, 2002). In the context of analysis of the economic value of geographical information, Alenka Krek (2002) referred to institutionalists (Eggertsson, 1990; North, 1990) and the impact of institutions on the behaviour of consumers. Armands Auzins (2004) introduced the reader to the theory of institutional economics. Later, Tommy Österberg (2006), again with reference to Douglass North and Hernando de Soto, stressed the difference between organisation and institution. Finally, Castelein and de Bruin (2007) used the transaction cost concept to make an economical assessment of the use of geo-information in agri-environmental policy. Institutional economics also provided the theoretical base for the European research action on 'Modelling Real Property Transactions' (ESF/COST G9, 2001; Stuckenschmidt, Stubkjær, & Schlieder, 2003; Zevenbergen, Frank, & Stubkjær, 2007).

The final documentation of the European research action includes several references to Searle's social reality theory (Stubkjaer, Frank, & Zevenbergen, 2007, p. 6; Ottens and Stubkjær, 2007, p. 153; Navratil & Frank, 2007, p. 225), so this theory surely counts among the other theories mentioned in this section. The reader is referred to the account provided in the context of the review of Bittner, above Section 3.4.

4.4. Stakeholder and social network analysis

Fundamentally, the development of cadastral systems and SDIs is based on collaborative action of actors within a society, often aiming at sustainable, national economic development. Within institutional economics (cf. Section 4.3), Bromley (1989) describes this type of human interrelationship as *institutional transactions*; it aims at changing rules through negotiations. Recently, Karikari et al. (2005) emphasised the importance of institutional transactions in land administration as follows, 'The Land Administration Project in fact insists that an agreement should be negotiated between stakeholders on the composition, structures and functions of the envisaged agency, noting that once this is done, the drafting of the appropriate legislation to implement the agreed institutional structure can begin' (p. 349).

The notions of 'actor' and 'stakeholder' are close to be synonyms, but stakeholder tends to be the wider term. A stakeholder is mostly defined as a person, group or organisation that is affected by, or able to influence, the outcome of the processes (cf. Silva, 2005, p. 33). These stakeholders usually have different interests and sometimes conflicting expectations, but they need not take a stance on the issue under scrutiny. These different perceptions and expectations can be detailed through a 'stakeholder analysis'. A stakeholder analysis tries to understand how stakeholders construct their worlds by means of seeking their objectives, values and expectations. It gathers and analyses qualitative information to determine whose interests should be taken into account when developing and/or implementing a policy (Schmeer, 2004, p. 3). Such an analysis would be useful when developing implementation methods for instance INSPIRE, (2009) directive in the European context and strategies for cadastral development projects in the developing countries context.

Interactions between public and private actors and organisations may be perceived as 'social networks'. Social networks can be understood as a net-like structure consisting of independent actors, or substructures that interact and cooperate with each other towards a shared goal. They are sometimes born out of the common interests of the partners, but some are designed so as to form an organisation (Kauppi, Lahdesmaki, & Ojala, 2003, p. 193). A quantitative analysis method, 'social network analysis' (SNA), is used for describing social ties of actors within a network in order to understand their pattern of relationship. It focuses on the way in which the configuration of networks enhances or constrains access to resources (Omran & van Etten, 2007, p. 700). As illustrated by Omran and van Etten (2007), SNA could be a useful tool to understand the distribution of spatial data.

5. Consolidating research efforts

This review of design research and of pertinent theory, respectively, has illustrated the manifold of approaches to inquiry into cadastral systems. However, the largely exploratory phase of this research also provides a base for suggesting a more comprehensive frame of inquiry, to be outlined in the following section.

5.1. Towards a paradigm for cadastral design research

As the wording of the research field indicates, research in cadastral *systems* finds its basics in systems theory. This theory has been further specified as actor-network theory (ANT), Socio-Technical Systems (STS), and social network analysis (SNA), respectively, approaches which each in their way name system components which appear in any cadastral system or SDI. By using these more elaborated theoretical frames in future research, research outcomes can be compared more easily, achieving a more consolidated knowledge. Comparing ANT and STS, it is proposed here to prefer STS, because STS includes the relevant elements of ANT and does not imply the ontologically questionable position that technology may function as an actor with intention. To corroborate this position, we distinguish technology in terms of software modules and services in the context of service-oriented architecture on one hand, and technical infrastructure on the other. While the former have actor functions within the information and communication system, the software services do not intentionally interfere with human and organisational interactions and change processes. ANT emphasizes the impact of information systems and infrastructures on change processes. However, this impact need not be conceived as originating from an actor, but rather as a precondition which restricts actors and their interaction. Such preconditions are researched within institutional economics under the heading of path dependency; STS in combination with institutional economic thus appears as a more adequate frame. Comparing SNA with STS, it appears that SNA focuses on a well-defined part of STS, namely the actor relationships. Finally, the relationship between STS and Searle's social theory is explored in recent research (Vermaas, Kroes, Light, & Moore, 2008; especially Cavanagh, 2008).

An important feature of systems theory is the distinction between the system and its environment. None of the mentioned theoretical frames seem to be specific on this issue. Here, soft systems methodology (SSM) fits well into the proposed, consolidated frame. By applying SSM, the researcher effectively specifies the focus area in its context, identifies the actors and their characteristics relative to the focus at hand, and thereby sets the scene for further elaborations based on STS and possibly institutional economics. When the research focus includes efficiency and effectiveness measures, institutional economics with its notion of transaction costs seems mandatory. Moreover, institutional economics also serve as a theoretical frame for the analysis of change processes, for example the national adoption of the provisions of the INSPIRE, (2009) directive, in terms of the notion of institutional transaction (cf. Bromley, 1989). The above considerations may be summarized in terms of a paradigm for cadastral design research as follows: STS seems an appropriate theoretical frame for the design of cadastral artefacts, possibly argumented with elements of Searle's theory. SSM seems mandatory for specifying the user environment of the artefact, while SNA applies where research focus includes analysis of actor relationships. Research into efficiency issues and into the adoption process of the artefact is well based on institutional economics.

5.2. A recall of the review in the light of the proposed paradigm

Would an application of the proposed paradigm have changed the outcome of the reviewed research? The proposal suggests the application of the SSM for framing the design of the artefact and assessing its potential benefits. Now, the researcher has to specify the users of the artefact: are they found among the staff of the cadastral agency? or in the wider group of governmental staff and professionals who are involved in real estate transactions? not to mention the end user in terms of owner or other right holder. In any case, a systematic account of the different perceptions of the people who are involved in or affected by the artefact tend to clarify the relevance of the invented artefact. Perhaps it is indicative for the potential of improvement that Table 2 above in the column Utility demonstration does not systematically refer to users.

As for the theory part of the proposal, mention is made that Effenberg explicitly applied the Zachman framework, which was not mentioned among other applied theories summarized in Section 4. The focus on design research may explain the use of the Zachman framework. More generally, theory is central to the research process (Frankfort-Nachmias & Nachmias, 1997, p. 20, p. 25ff) so the proposal provides for a better outset for future research.

5.3. Discussion and further research

The above results were achieved by adopting a design research paradigm. As mentioned in Section 1, the design research paradigm has a complementary behavioural research paradigm, and in Section 3, we referred to Roux and Barry (2009) who assessed other paradigms. Moreover, our focus was on cadastral research, assuming that research in GISs and SDI adopts very similar approaches. Further research is needed to relate to these efforts. The empirical base of such research should comprise not only of research on information science aspects, as have been the basis for this article, but also of research addressing land tenure and other social science aspects, cf. Çağdaş and Stubkjær (2009). Compared to the review by Akingbade et al. (2009) of literature on the impacts of GIS in governmental and non-governmental organisations, the present review focused on methods and theoretical frames which support analyses and explanations of the positive or negative impacts observed. Especially, their finding that '[h]uman and other contextual factors that shape the impacts of GIS can be better understood by applying theories to understand how a system is configured and introduced for a particular application' (p. 104) agrees with ours. Similarly, a recent research carried out by Grus et al. (2010) presented a theory driven precise analysis for developing a better understanding of complex mechanisms and forces that shape SDI's by applying complex adaptive systems theory. Apparently, several research groups have not only a shared intentionality of establishing a base for more rigorous studies of cadastre, GIS and SDI, but also provided outlines of its components.

6. Concluding remarks

Cadastral research gained momentum during the last few decades, in part because the use of computer technology eased comparisons across countries and jurisdictions. Informed by philosophy of science, this article distinguishes between cadastral research which aims at describing phenomena, and cadastral research which aims at designing artefacts. This article proposed a paradigm for the latter portion.

As the methodology part of the paradigm, the *design research methodology* was introduced. Five recent dissertations and ISO/WD 19152.3 Land Administration Domain Model were used as the empirical base for testing the proposed paradigm. The result of this analysis showed that all reviewed research, in our view, corroborates the relevance of the design research methodology introduced. The lack of clear theoretical bases in the reviewed research prompted us to review theoretical underpinnings of cadastral research. The second part of the article, therefore, documented a number of theories which are often used in cadastral research including (general) systems theory, actor-network theory, and institutional economics. The theory part of the proposed paradigm presented in Section 5 may be criticized as it is not exhaustive. However, the purpose was not to present a synthesis for a whole body of theories, but rather to contribute to the integration of mainstream theoretical approaches. A paradigm for research which aims to create and evaluate cadastral IS artefact was presented and corroborated, including a consolidated theoretical frame. Finally, further research issues were identified, drawing also on other related research reviews.

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