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An Evolutionary Approach to Technology Innovation of Cadastre for Smart Land Management Policy

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Abstract: In this study, we attempted to quantitatively determine the characteristics of keyword networks in the cadastre field using major contents of research drawn from international academic papers. Furthermore, we investigated the macroscopic evolution of cadastral research and examined its keyword network in detail (at a global scale) using semantic analysis. The analysis was carried out based on cadastral-research-related publications extracted from "Scopus" for 1987 to 2019. It was found that cadastre research has closely followed the recent trend of a growing interest in research on geospatial information and standardization. The results showed the advancement of technology innovation within the field of cadastres, as highlighted in the combination of relevant keywords (mostly from those related to spatial information technology and participation of civilians). These new issues are expected to drive the evolution of the academic scope in the future through synthesis with other fields for smart land management policy.

Keywords: cadastre; technology innovation; land administration; land management; land-use; semantic analysis; keyword network

1. Introduction

The key to understanding the development of modern cadastres is realizing the importance of cadastres in the relationship between humankind and land. With the advent of the digital age, the field of cadastral research has developed through innovations in land management and ownership based on land parcels (2D) and floor plans (3D) [1–5]. Owing to information and communication technology (ICT) advancements, cadastral research has advanced through collaboration with other fields [6,7]. Research shows that the development of cadastral research is strongly correlated with the adaptation of advancements in the information and communication industry in developing countries [8].

In particular, the scope of cadastral research has been enlarged from laws and systems to include geographical-spatial information using new technologies and services. With the help of technological developments, this has changed the previously government-friendly role of cadastres in distinguishing ownership into a more user-friendly role. Thus, to confront the changes such developments will bring to cadastral research and facilitate future studies, there is a need to organize and analyze cadastre studies across various fields. The purpose of this research is to analyze cadastral research evolution from international research papers using semantic analyses (based on macro- and microscopic perspectives) and deduce the flow of research.

A cadastre can be referred to as a register where boundary information is recorded. It also includes the graphical presentation of real property units: the boundaries between plots are determined in order to divide ownership. These boundaries are registered via a digital cadastral map. The registered information, which has legal implications for land use and ownership, is divided into a time series that contains diverse attributes and overlays. As studies on land use [9] or landscape changes [10] have shown, cadastral research is evolving to allow for more elaborate analyses carried out using diverse data sources. Regarding the extension of the scope of cadastral research, studies on enhancing the efficiency through social scientific approaches to cadastral research along with those that support the concept of land ownership by following existing laws and institutions [11,12] have been carried out.

Although studies of the application of new technologies for use in cadastral research have continued [13–15], Silva and Stubkjær [8] showed that issues relating to societies, politics, and economics play a significant role in the advancement of cadastral research. In fact, from 1995 to 2020, 18.2% (1199) of the papers published in the field of cadastral research were categorized as "social science" (scopus.com 28 Jan, 2020). However, as significant technological advancements in cadastral surveying have been made with the adaption of geographical/spatial data and ongoing changes in the data environment (an increase in the availability of public data with open sources), further evolution in this field is predicted.

Cadastral research involves the setting or readjusting of boundaries between real estate areas and is important in the production of legal effects for properties. As cadastral research is related to people and institutions, this study has suggested semantic analyses for the advancement of cadastral research.

Furthermore, global research trends [16–20] and other specific topics have also been analyzed. Research on multiple topics have used bibliometric analysis [21–27]. The review policies and analysis topics focused on using co-authors or co-words [28–34]. Moreover, there is a study that monitored the development process by analyzing trends and issues on specific topics [10,35]. There is also a study on the evolutionary process in the cadastral field [35,36]; however, the study does not discuss the methods for evaluating the evolutionary processes (quantitative analysis or semantic network analysis of major keywords).

2. Research Methodology

This research utilizes social network analysis and semantic analysis to investigate the evolution of cadastral research. For the social network analysis, the programs NetMiner and VOS viewer (visualizing scientific landscapes) were used to visualize the network. To examine the microscopic and macroscopic structure of the network aspects, we attempted to visualize the structural changes in the network with respect to time, analyze the centrality index for the entire network, and determine the density for each group.

The search was carried out using the index word "Cadastral," with the analysis period extending from January 1, 1987, to December 31, 2019. Information, including the titles, abstracts, and keywords of the identified papers were extracted.

A social network can be used to understand resource exchanges on the basis of factors such as manpower, institutions, and fields of research [37–40]. Based on a review of previous studies, we designed our methodology and identified the structures of the networks. The centrality index in keyword networks for each group were analyzed and identified through our network analysis, and the density of each group was identified from its networks. Thus, we were able to interpret the networks identified in each group to highlight the current trends in the field of cadastral research.

In this study, we used the following process:

1. Data were extracted from www.scopus.com (3548 papers in total) using the keywords "cadastral" that included major keyword such as "cadastre," "cadastration," and "land administration," which most frequently used words in cadastral fields. Research information was extracted from the following databases: the Web of Science (WoS), SciFiner, and Google Scholar; the functionality of these databases is similar to that of Scopus. Combining these search engines is expensive and time-consuming, and leads to overlapping results. We therefore selected Scopus, which is the most comprehensive database.

   We extracted nouns from the data from 1987 to 2019 and generated inter-keyword matrix and inter-network matrix data.

2. We visualized the evolution of cadastral research using VOS viewer to examine temporal changes in the keyword network.
3. We used social network analysis to group the data, and high-frequency keywords were selected for further consideration.
4. We analyzed high-ranking keywords using centrality index comparisons.
5. Based on institutional network analysis results, we attempted a two-mode network analysis to understand and present institutional relationships.
6. We attempted to understand the intergroup network in detail through group density analysis.

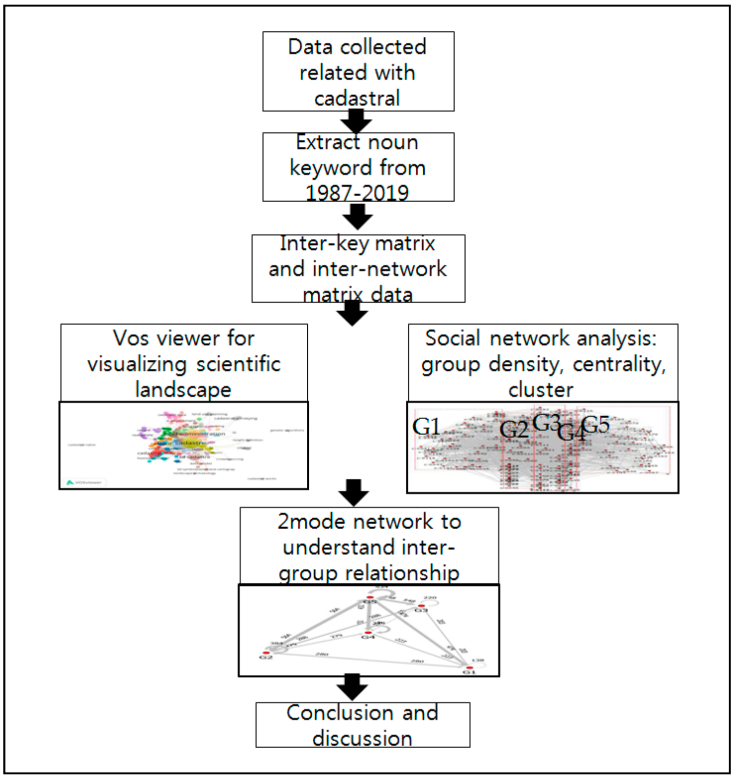

Figure 1. Research process.

NetMiner was used to evaluate the social network analysis evaluating network structure of the keyword network for exploratory analysis and visualization of large network data (netminer.com). VOS viewer was used to map the keyword network as a time series. The distance between the nodes that appear in the network, visualized by NetMiner and VOS viewer [41], represent the intensities of relationships.

Cho and Kim [42] used social networks and data mining to analyze complex relationships between academic fields by extracting the central keywords of each field, along with the connecting keywords used to link different fields. Furthermore, other studies have investigated the structure of knowledge using keywords from diverse academic fields [43–47]. The keywords describe the main topics of academic papers.

The central and connecting keywords are extracted through correlation analysis, and, a network of all keywords is constructed based on the results. This paper presents a linked keyword method that provides a template for building keyword networks using text mining.

We analyzed the keywords extracted from various papers. An intelligent morpheme analyzer was used to preprocess the data, and TI.exe was used to build the network matrix [48–50]. NetMiner was used to build a matrix for network analysis (as visualization of large network data is easier). Network structures were identified by analyzing the group density, the centrality index, and the spring-KK, as well as performing a cluster analysis. The characteristics of each network group were also analyzed. As a result, the total number of network links was 2387, the density was 0.108, the average degree was 16, and the average distance was 1907. These attribute analysis values represent keywords on the network and help quantify and interpret the relationship between major keywords.

3. Results

3.1. Evolutions Over Time

To define the official concept of the cadastre, the International Federation of Surveyors established a working group in 1992 to clarify a "The FIG Statement on the Cadastre" [51]. The statement explains the cadastre as an "up-to-date land information system containing a record of interests in land. It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements." The FIG cadastral concept is shown in Figure 1.

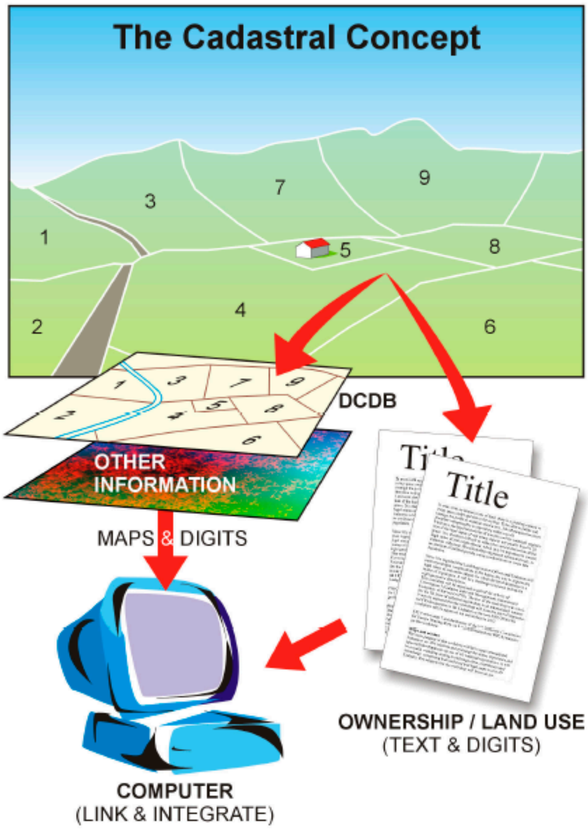

Figure 2. The FIG Statement on the Cadastre [52].

In 1980, the Digital Cadastral Data Base (DCDB) in Figure 2 was formed, and cadastral records were computerized. During the 1990s, land administration improved with the development of the internet. Cadastral maps and cadastral data were developed (alongside other technologies in computing) using the internet after 2000 [52,53].

The first period, before 2001, was characterized by the computerization of cadastral maps through computer programs such as geographic information system (GIS). In the second period from 2002 to 2007, the use of digital cameras in papers relating to land registration steadily increased. In 2005, the cadastral maps of keyword network maps were used as a source of information that integrated various projects led by the government, such as land, real estate, and local operations [30]. In this period, the capacity was developed to manage land, ownership, limits, and obligations; this formed the foundation of sustainable improvement [54]. In 2007, volunteered geographical information (VGI) was introduced, which led to a shift from government-led cartography to citizen-led cartography [55–65]. Additionally, the iPhone was introduced in this period, changing people's lifestyles and producing services optimized to individual preferences.

During the third period, which extended from 2008 to 2019, papers related to land administration (based on spatial information) were released. Taking advantage of these developments and to keep pace with globalization, this study attempted to identify the evolution of cadastral research objectively and in a time-sequential manner, by building a knowledge map based on the four periods. The map was divided in accordance with the characteristics of each period to present the limitations and future directions. Scopus provided the keywords for the contents of the study. In this study, the keywords were used to build the keyword network.

In 2008, the global economic crisis led to changes in cadastral policies, providing another opportunity to spread awareness of the importance of land administration and ownership rights. From 2010, the ability to an update data became the foundation to solve various social problems confronted by cadastres and land administration. In addition, the spatial data based on land administration, along with the open-data policies of governments, provided the opportunity to reconstruct data-based city infrastructures.

1987 to 2001: Figure 3 shows the four major keyword network sections: "cadastre," "sustainable development," "land administration," and "land tenure." The initial studies on cadastres were carried out for real estate, land evaluation, map interpretation, and cadastral maps. In particular, land evaluation and the assessment of land performance using cadastres were the focal points. Williamson [66] considered why the role of the cadastre system was gradually becoming more important to policymakers (particularly in developing countries). This study suggested that the cadastral system adapted the needs of each country such as regularization of land rights and establishment of systems.

Along with the evolution of cadastre and land administration systems [67–70], studies have investigated the expansion of keyword's scope to include land information system (LIS), GIS [71], and spheres relating to new spatial information [72].

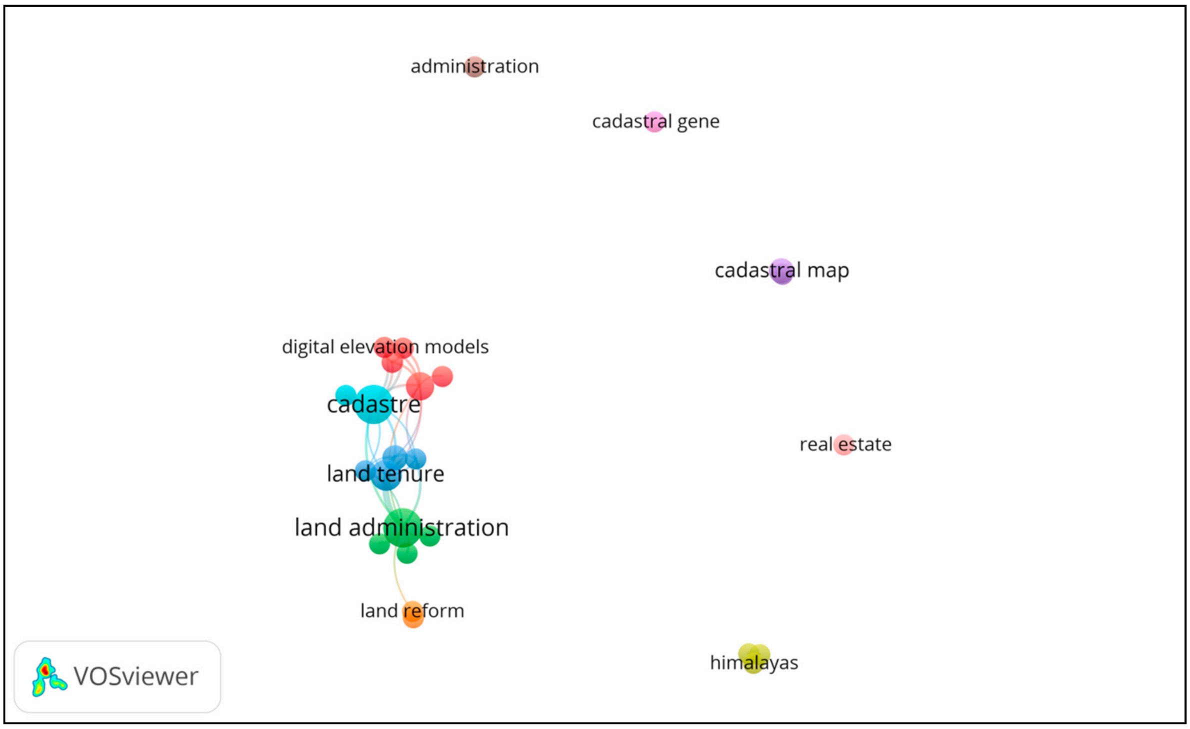

Figure 3. Keyword network map 1987–2001.

*Regarding the color of the circle in VOS viewer, it is determined by the score of the item ranged from blue, green, to red. All label is visualized avoiding overlapping labels. It can be used different ways of coloring items to drop down the colors [41].

2002–2007: More keywords were observed in the keyword networks from this period than in those from the previous period (see Figure 4). The scope of the cadastre and land administration fields was extended through the incorporation of ICT terms (e.g., "digital data base," "3D cadastral data models," "cadastral data," and "digital cadastral map"). This implies that the cadastre approach that was developed in the 18th century was changing. In particular, during this period, the scope was actively extended to include the field of spatial information, and the "GIS" network was formed. Notably, this period launched cadastral template 2.0 in the annual meeting of FIG-commission, which was developed by research group for SDIs and land administration based on 17 data fields (see cadastral template 2.0 homepage).

Benhamu and Doytsher [73], and Stoter and van Oosterom [74] discussed 3D cadastres, in which the utilization of land registration and geodetic survey data in four dimensions are considered. It has been reported that this approach was used to extend the 2D cadastre of Israel to 3D.

Williamson [66] explained the history of the development of land administration and has predicted research methodologies, while other discussed the future of land administration centered on the value, use, and development of land ownership. In particular, the early 2010s can be regarded as a period in which information pertaining to cadastres and land was considered valuable to spatial data [75]. Thus, in 2005, land, real estate, and cadastral data provided the potential for smooth maintenance of complex controls over land, rights, limits, and obligations for the development of various government projects [76], such as planning and developing land and local operations [54,55], which are connected to core cadastral domain model (CCDM) [77] and e-LA [78]. During this period, the networks between the main keywords grew stronger than during the previous period (when the scope was extended). The development of cadastral research involved division into three fields: "cadastral map," "cadastral data," and "land administration." Above all, this period marked the emergence of "cadastral" and "land" as the central keywords; furthermore, networks formed with GIS were confirmed during this period.

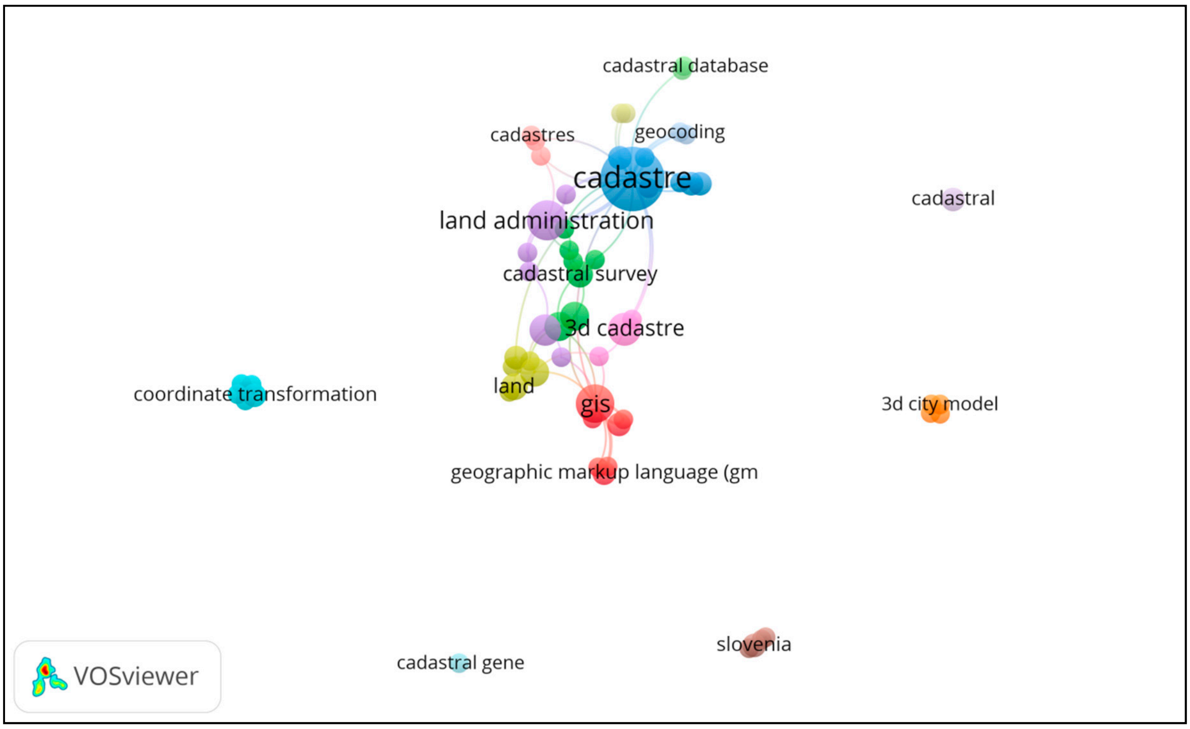

Figure 4. Keyword network map 2002–2007.

2008–2014: During the most recent period, the overall shape of the keyword network changed. When compared with the previous keyword networks, the results showed that mainstream research subjects were being created and that keywords such as "cadastral," "cadastral map," "information system," "cadastral plan," and "land registration" were advancing as stronger core streams (see Figure 5).

In the late 2000s, cadastral data records were researched. The construction of metadata automation has allowed the metadata of spatial data to be updated automatically. This enables the user to build "information in hand" environment (that the user is comfortable with), overcoming the need to generate and update metadata [72]. As VGI [79] signifies voluntary participation in cartography, it is expensive and requires a large amount of effort (as for the production of earlier cadastral maps). This allowed people to get involved in cadastral surveys and producing cadastral maps using personal hand-held GPS equipment or satellite images. It allowed the collection of cadastral data using open-street maps and the collected data could now be utilized online through open platforms.

This study covered technical aspects using a 3D hybrid cadastre model [80], and the results showed that 2D cadastres changed to 3D cadastres owing to urbanization and the use of underground and above-ground spaces. This research proposed that effective 3D modeling should be carried out by incorporating spatial databases, 3D GIS, and computer-aided design (CAD). We proposed that 3D cadastre modeling should be performed by combining the existing 3D cadastre modeling methodologies. Advancements were made through the adoption of analysis methodologies, including the cadastral and spatial information fields that emerged at the beginning of 2000, which has enabled us to confirm the expansion of the knowledge network in the field of cadastral research.

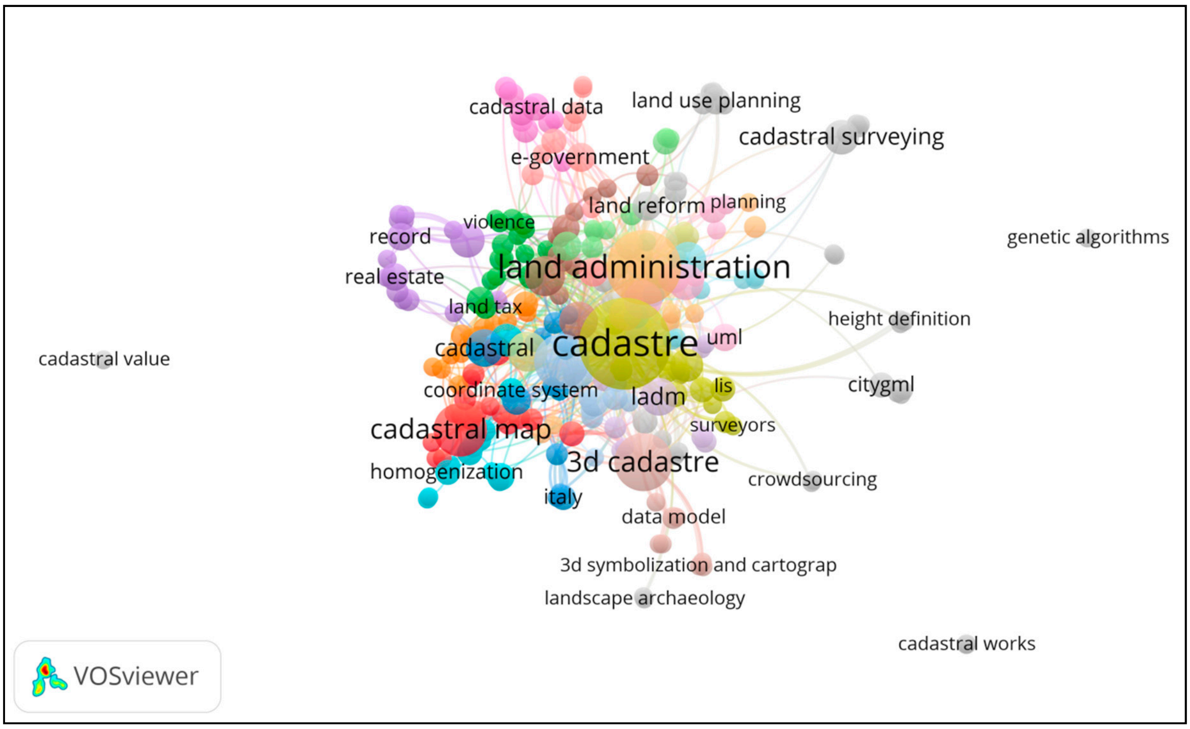

Figure 5. Keyword network map 2008–2014.

2015–2019: More keywords were observed in the keyword networks from this period than in those from the previous period. The scope of the cadastre and land administration fields was extended through the strengthening cadastral survey such as land cadastre, mapping, and real estate etc. Those trends show self-organization that was developed technology innovation in the land administration and cadaster (see Figure 6).

Yang [81] investigated effective coordinate transformation on cadastral maps that utilized the World Geodetic System for the cadastral reform project. They proposed a method for providing clear and accurate cadastral maps through cadastral reform projects that corrected mapping errors. In a study on neo-cadastre [82], which represents another new trend in the cadastre field, VGI enabled individual citizens to make maps or write land tenures. The study used examples from three nations (Ghana, Canada, and Indonesia) to demonstrate the best method for considering land tenure rights that are based on the opinions of individuals and not on rules of laws from a national authority. Based on experiences from Latin America and Albania, it was suggested that accurate GPS and geodetic infrastructure should be built to develop the field of cadastral research in developing countries.

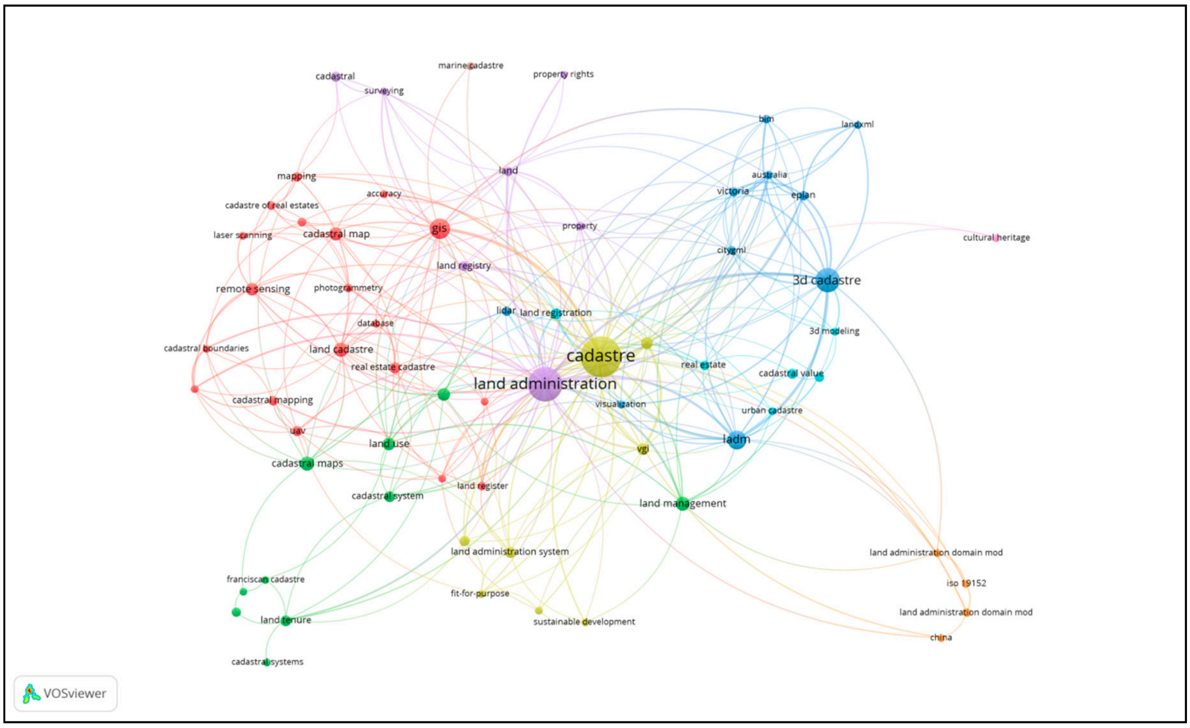

Figure 6. Keyword network map 2015–2019.

3.2. Network Characteristics of Cadastral Research for Technology Innovation

3.2.1. Characteristics of Cluster Network

Group analyses of data mining involves assigning objects to groups in which each object shares similar attributes [83]. In this study, group analyses by keyword's code were utilized to extract diverse features related to cadastres, and by utilizing the specific information for each group, this method allowed for the prediction of key research subjects in the field of cadastral research (see Figure 7).

The structural features of the network analyzed using the keywords extracted from the international academic papers published in the field of cadastral research from 1987 to 2019 were as follows: when keyword network was analyzed using the cluster network technique, five groups were formed. The keywords in each major group were as follows: GO covered issues relating to cadastres and real estate that contained the words "cadastre" and "cadastral map" G2 contained keywords relating to the legal system of cadastres, with primary keywords including "land register," "property right," and "land reform." G3 contained keywords concerned with "land registration," "cadastral system," "real estate by cadastral," and content related to land management where cadastre and ICT were combined. Those trends related to the direction of sustainable land use utilizing cadastres, and the keywords included "sustainable development," "coordinate system," and "ownership." G4 featured issues related to urban planning and the context of land management, with new keywords such as "land information system" and "real estate," etc., appearing in the works of Carmona et al. [84], Andrieu et al. [85], Smith et al. [86], and Gridan et al. [87]. The keywords in G5 were related to land use and the data generated during the digitalization of cadastre, such as "spatial data infrastructure" and "LADM (Land Administration Domain Model)," etc. As the groups include issues related to cadastres, by analyzing cluster networks, it is possible to utilize each group and highlight the overall evolution of the field of cadastral research.

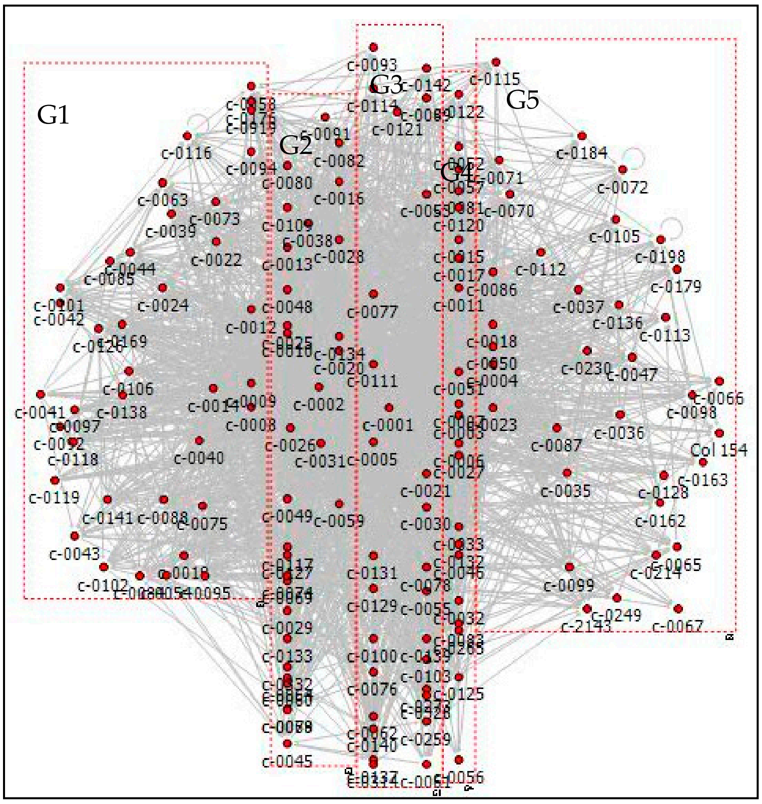

Figure 7. Cluster network structure of cadastral research.

3.2.2. Network Structure Using the Centrality Index

The keywords with a high centrality index included "property rights," "cadastral survey," "aerial photographs," and were related to "GIS," "LIS," and "spatial data," where cadastres and technology were combined. Furthermore, it was confirmed that keywords related to cadastral data and information had a high centrality index and could be considered the core keywords reflecting the latest research trends.

When we considered the upper-level nodes based on the nodes' betweenness centrality, we identified diverse keywords relating to new technologies in the fields of cadastral research and spatial information. High degrees of centrality index implied that the nodes were used with other keywords in papers, and the structure of the extended network for cadastral research was confirmed through the analysis of the results. GIS was found to belong to the same group of words as "land administration," "cadastral system," and "real estate," and showed high centrality for issues related to cadastres and real estate.

Closeness centrality represents the keyword at the center of the network, and researchers with an interest in the field of cadastral research can easily identify its evolution by carrying out a search for keywords with high closeness centrality.

3.2.3. Group Network and Group Density

G2 and G5 formed a relatively large number of networks (564); this highlights the combination of new issues related to future continuous land use, such as the environment and landscape ecology. On the other hand, G3 and G4 showed a relatively small number of networks (199), implying that it is difficult to consider studies on the legal systems related to cadastres as new issues. The results confirmed that G2, G4, and G5 are the created legal systems in land use for urban planning (see Figure 8).

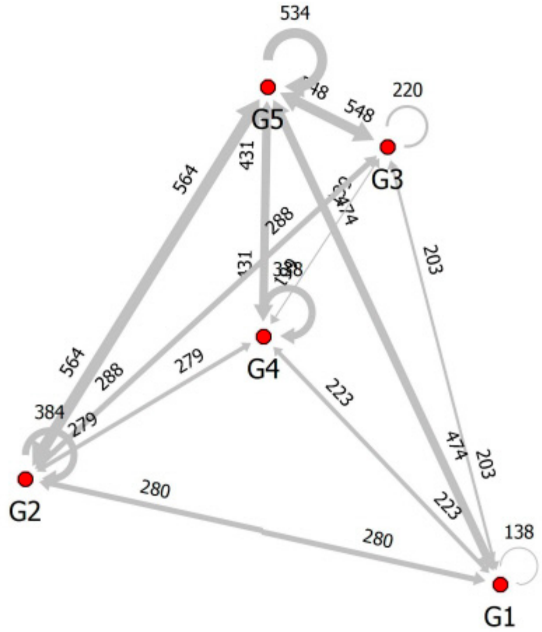

Figure 8. Group network—Two mode network.

The networks of each group obtained from cluster networks based on group density are shown using the spring-KK technique (Table 1). The indices of group density were as follows: the segregation matrix index (SMI), External-internal index (E-I), and cohesion indices were utilized for group analysis, and were used to compare grouped individual attribute units with other groups on the basis of network density, number of links, and degree of concentration. When we considered the density of each group in the analysis results, G5 had the highest density (showing a value of 0.619), followed by G2 and G3, which showed values of 0.54 and 0.529, respectively. Among the cadastre studies, issues related to legal systems showed a high density; in particular, the results showed that legal system keywords were used in connection with the keywords of other groups.

Table 1. Group density.

	Density	E-I index	SMI	Cohesion Index
G1 (real estate)	0.324	0.755	0.015	0.629
G2 (legal system)	0.54	0.66	0.145	0.644
G3 (land administration)	0.529	0.668	0.306	0.824
G4 (urban planning)	0.386	0.765	0.305	0.858
G5 (land use)	0.619	0.663	0.144	0.713

Issues related to cadastres and real estate also showed high densities, implying that there was a significant correlation between cadastre and real estate issues. The E-I index compares the number of internal links within a group with the number of external links shared with other groups; if the E-I index is 1, all the link nodes are from other groups. Accordingly, the fact that the E-I indices of G1, G3, and G4 were 0.755, 0.668, and 0.765, respectively, showed that many link nodes of these groups were from other groups. This result showed that many issues related to continuous land use in the context of cadastres were linked with other groups; in particular, broad keywords were generated as academic synthesis resulted from the combination of cadastral and spatial information. The SMI index, which represents the degree of separation between groups, compares the density within a group and the link density between groups, with "other" meaning that groups are completely separated G3 also had a high cohesion index and density index, which showed that there is a close relationship between the keywords related to legal systems (e.g., cadastral law).

Group density can have a value between 0 and 1. The E-I index is the calculated ratio between the numbers of external links to other groups and the internal links within a group. It varies between −1 and 1; the closer the value is to −1, the greater the number of the internal links within a group; values closer to 1 indicate a greater number of external links with other groups. The SMI index is the ratio between the density of the external links to other groups and the density of the internal links within a group. It has a value between −1 and 1. Unlike the E-I index, the closer the value is to −1, the higher the density of the external links to other groups; the closer the value is to 1, the higher the density of the internal links within a group. The cohesion index is the value obtained by dividing the density of the internal links within a group and the density of the external links to other groups. If the value is 1, the density of internal links within a group is equal to the density of the external links to other groups; if the value is bigger than 1, the density of links within a group is higher.

4. Conclusions and Discussion

4.1. Conclusions

This study analyzed the international cooperation trends and research subject patterns in the field of cadastral research for over 30 years (1987–2019). By considering cadastre-related papers on a year-by-year basis, we were able to observe the evolution of the cadastral research, along with that of the field of spatial information, which evolved to incorporate ICT. For example, academic papers in the field of cadastral research showed a steady evolution up to 2005; however, a rapidly increasing trend after 2005. This study not only combined the research methods of semantic analysis and keyword network, but also determined the characteristics of each group, analyzed the group networks, and extracted the centrality and density indices. This analysis has provided objective and qualitative evidence for the process of evolution in the field of cadastral research.

To summarize the progress of cadastral research, we found that there were common parameters, such as property rights, spatial data infrastructure, LADM, etc. Maintenance of these parameters has come to the fore, with increase in interest in the development of open data. Methods that handle cadastral research are changing rapidly with the development of technologies (such as photogrammetric, remote sensing, 3D, etc.). We predict that henceforth, various methods that handle the new aerial and marine surveying techniques will be incorporated into cadastral surveying. We found that the essence of cadastral research has not changed over time but, as with many other fields, the methods have diversified. The evolution process before 2001, studies on cadastres were generally characterized by content related to analog cadastres. After 2000, the field evolved from paper-based land administration system (LAS) to online LAS through the use of the internet. Results showed that from 2000, through the advancement of the internet, the field of cadastral administration advanced by merging with online LAS, and the research field related to the integration of SES steadily developed. Furthermore, studies of legal systems were carried out after 2005 to reduce land disputes through the revision of cadastral maps. Our research intended to provide empirical evidence that the progress of this field involved combining cadastral and spatial information based on land administration systems for sustainable development [88–90]. However, by performing a keyword network analysis, this study quantitatively proved that cadastres and spatial information are evolving. These keywords reflect the critical role of SES in cadastral surveys. Interestingly, SES received more attention in these early years. This was probably due to the good land governance of land administrations, which was integrated with global agendas and looked to achieve sustainable development [91].

Regarding the legal systems, the field of cadastral research is closely related to "ownership," which implies that the issues related to legal issues of cadastres should be included through synthesis with other fields, rather than formation of stand-alone issues. Accordingly, this field require to incorporate the diversity of related studies through academic synthesis with other fields.

4.2. Discussion

The results showed the advancement of technology innovation in cadastres, as highlighted in the combination of the relevant keywords majorly from those related with spatial information technology and citizen's participation. This trend confirmed that open data have emerged as new issues as spatial data utilization. These issues are combined with solving social issues, such as crime prevention and management vacant house. Thus, in time, standardization of spatial data cadastral research will be challenging; these new issues are expected to drive the evolution of the academic scope in the future through synthesis with other fields.

One characteristic that has recently become prominent in the evolution of research on cadastres is that cadastre-related services standardized by the use of smart technology have been promoted. This is related to the advancing policies of different countries, including open data, although policies face some limitations depending on each country's conditions for land administration.

Another phenomenon is the direct participation of civilians in producing cadastral maps, as in VGI. Cadastral work is shifting from a government-led, top-down field with passive participation into a field involving voluntary civilian participation. The roles of land administration are evolving into a system that maintains new 3D and 4D registration matter above and below the subject land, along with systems in which real-time updates are possible. In the future, a legal basis must be established to enable changes that will allow for an environment where the registration maintenance of rights that account for environmental changes can be updated in real time. The role of cadastres in providing legal bases for land ownership rights and land readjustments must continue. However, methods that deal with cadastres must also be continuously updated for smart land management policy.

Through semantic analysis, previously unknown information can be obtained by extracting valuable data from extensive data pools. Although diverse information about studies in the field of cadastral research can be obtained using various techniques, it is unclear how these data can predict which future technologies will facilitate the advancement of cadastral research.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

SMI, E-I, and cohesion index are used for group density analysis, that compares with other group by link, density and cohesion in network. The mean of SMI (segregation matrix index) created by Fershtman and Chen. SMI = (d_AA–d_AB)/(d_AA+ d_BB), where d_XY means density of choices from X to Y. If group A segregates (reveals self-preference), SMI > 0. In the extreme case where A segregates completely, its members direct no choice outward, SMI = 1. In contrast, where A's members reveal other-preference, it will direct all their choices outwards, SMI = −1. Density described giving densities for each group. E-I index compares the number of links between actors of the same type and between actors of different type. The index ranges between −1 and 1, −1 indicating that all ties connect nodes of the same type and vice versa. Cohesion index described the extent to which ties are concentrated within a subgroup, rather than between subgroup (see Tables A1 and A2).

Node-betweeness centrality: This measured by the extent to which a node lies between all other pair of nodes on the geodesic path. They behave in a similar way to "broker" by bridging between nodes.

Closeness centrality: This module analyzes centrality of a network structure based on geodesic distances among the nodes. centrality is measured by the inverse of the sum of distances from a node to all the other nodes, which is then normalized by multiplying it by (n-1)(Netminer manual).

Table A1. Major issues in cadastral research by Group.

G1 (real estate)			G2 (legal system)			G3 (land administration)			G4 (urban planning)			G5 (land use)		
Keywords	**Code**	**N**	**Keywords**	**Code**	**N**	**Keywords**	**Code**	**N**	**Keywords**	**Code**	**N**	**Keywords**	**Code**	**N**
Cadastre	c-0001	136	cadastral	c-0008	15	Land administration	c-0002	80	3D cadastre	c-0003	39	GIS	c-0004	38
Cadastral map	c-0005	32	Cadastral survey	c-0009	15	Land registration	c-0010	15	Cadastral maps	c-0006	19	Land use	c-0018	10
Stable cadastre	c-0021	9	Land tenure	c-0012	13	Land registry	c-0013	12	Land cadastre	c-0007	18	land	c-0023	8
Administ ration	c-0030	6	Property rights	c-0014	11	Cadastral system	c-0016	10	Cadastre	c-0011	13	Land adminis tration system	c-0035	6
Property	c-0077	4	Land reform	c-0019	9	Real estate cadastre	c-0020	9	Cadastral surveying	c-0015	10	Marine cadastre	c-0037	6
Coordinate transfor mation	c-0061	4	Cadastral data	c-0022	8	LADM	c-0026	7	GPS	c-0017	10	Land adminis tration systems	c-0036	6
3D property	c-0053	4	Land register	c-0024	8	accuracy	c-0025	7	Real estate	c-0027	7	Land use planning	c-0047	5
Building cadastre	c-0055	4	Turkey	c-0039	6	Sustainable development	c-0028	7	Datab#ase	c-0033	6	Spatial data infrastructure	c-0050	5
Data model	c-0062	4	Cadastral database	c-0040	5	uml	c-0029	7	Cultural landscape	c-0032	6	Housing	c-0065	4
Photogra mmetry	c-0076	4	Cadastral parcel	c-0044	5	Record	c-0038	6	Topology	c-0051	5	Italy	c-0066	4
Public good	c-0078	4	Cadastral information system	c-0041	5	Aerial photographs	c-0031	6	Urban planning	c-0052	5	Land markets	c-0070	4
Utility cadastre	c-0089	4	Cadastral manage ment	c-0042	5	Cartography	c-0045	5	Land information system	c-0046	5	Land rights	c-0072	4
			Cadastral mapping	c-0043	5	Ownership	c-0048	5	Cadastral measure ments	c-0057	4	Spatial data	c-0086	4
			Geographic information system	c-0063	4	Parcel	c-0049	5	Cadastral gene	c-0056	4	Standar dization	c-0087	4
			Cadastral resurvey project	c-0058	4	Land management	c-0069	4	Reeng ineering	c-0081	4	Land adminis tration domain model (ladm)	c-0067	4
			Management	c-0075	4	Cadastres	c-0059	4	Remote sensing	c-0083	4	Land parcel	c-0071	4
			Surveying	c-0088	4	Coordinate system	c-0060	4						
			Australia	c-0054	4	Homoge nization	c-0064	4						
			Landscape change	c-0073	4	Land consolidation	c-0068	4						

Table A1. *Cont.*

G1 (real estate)			G2 (legal system)			G3 (land administration)			G4 (urban planning)			G5 (land use)		
Keywords	Code	N	Keywords	Code	N	Keywords	Code	N	Keywords	Code	N	Keywords	Code	N
			Rural landscape	c-0084	4	Land tax	c-0074	4						
			Slovenia	c-0085	4	Real property	c-0080	4						
						Registration	c-0082	4						
						Real estate property	c-0079	4						

* The name of each group indicates representative issues.

Table A2. Centrality index in the keyword network.

Keywords	Code	Group	Num.	In-Degree Centrality	Rank	In-Close ness	Node Betweenness Centrality	Eigenvector Centrality
Property rights	c-0014	G2	11	10.28859	1	0.873656	0.061366	0.480301
Cadastral survey	c-0009	G2	15	4.47651	2	0.767338	0.065728	0.203429
Aerial photographs	c-0031	G3	6	3.738255	3	0.700613	0.020025	0.179902
GIS	c-0004	G5	38	3.369128	4	0.662223	0.105017	0.257324
Land administration	c-0002	G3	80	3.208054	5	0.763299	0.203193	0.370056
3D cadastre	c-0003	G4	39	1.57047	6	0.622433	0.037929	0.119734
Cadastral maps	c-0006	G4	19	1.328859	7	0.584786	0.027394	0.107867
Spatial data infrastructure	c-0050	G5	5	1.201342	8	0.599284	0.017262	0.071226
Land registration	c-0010	G3	15	0.979866	9	0.519809	0.009563	0.128593
Record	c-0038	G3	6	0.979866	10	0.559949	0.004723	0.073295
LADM	c-0026	G3	7	0.959732	11	0.56212	0.016535	0.075544
Real estate	c-0027	G4	7	0.912752	12	0.564307	0.042504	0.099772
Land registry	c-0013	G3	12	0.744966	13	0.529295	0.009868	0.066123
Land cadastre	c-0007	G4	18	0.724832	14	0.537136	0.015275	0.101859
Cadastral	c-0008	G2	15	0.711409	15	0.547271	0.087137	0.245886
Governance	c-0111	G1	3	0.691275	16	0.573229	0.009751	0.03124
Cadastral map	c-0005	G1	32	0.684564	17	0.545214	0.02987	0.115427
Real estate cadastre	c-0020	G3	9	0.604027	18	0.529295	0.006791	0.052356
Standardization	c-0087	G5	4	0.597315	19	0.541145	0.005873	0.02907
GPS	c-0017	G4	10	0.503356	20	0.531234	0.004141	0.036368
Marine cadastre	c-0037	G5	6	0.503356	21	0.533187	0.001397	0.033155

Table A2. *Cont.*

Keywords	Code	Group	Num.	In-Degree Centrality	Rank	In-Close ness	Node Betweenness Centrality	Eigenvector Centrality
Cadastral data	c-0022	G2	8	0.463087	22	0.529295	0.006733	0.040941
Stable cadastre	c-0021	G1	9	0.42953	23	0.521679	0.004719	0.035984
Land use	c-0018	G5	10	0.416107	24	0.523563	0.016884	0.097905
Multipurpose cadastre	c-0127	G3	3	0.416107	25	0.51428	0.001374	0.028968
Cadastre	c-0011	G4	13	0.409396	26	0.52737	0.004459	0.032614
Cadastral database	c-0040	G2	5	0.369128	27	0.51428	0.003961	0.025503
DAZD (State archive in Zadar)	c-0136	G5	3	0.369128	28	0.507087	0.001656	0.01806
Land register	c-0024	G2	8	0.33557	29	0.480221	0.003747	0.041502
Surveying	c-0088	G2	4	0.33557	30	0.52737	0.005663	0.031123

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