

Article

Bibliometrics on Public Utilities Registration Research

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Abstract: Public utilities, such as electricity, water, heat, oil, gas, and electronic communication, are a vital component of every modern society. With rising urbanisation, more complex buildings and infrastructure, underground and overground construction, as well as a limited amount of space in such areas, the proper registration of utilities has become more important than ever. A bibliometric analysis was conducted on the research topic of public utilities' registration. On publications retrieved from the Scopus database concerned with the topic of public utilities in land administration a bibliometric performance analysis and a scientific mapping analysis were conducted. A total of 241 publications containing the keyword 'utilities' or 'infrastructure', together with the keyword 'cadastre' or 'land administration', in their titles, abstracts, or keywords were selected for this research. The outcomes of the performed analysis were also compared with the outcomes of analysis of publications concerned with land administration research in general. Our results revealed that research conducted on the topic of public utilities registration has increased but is still rare compared to the research conducted on land administration in general. Our results also showed the importance of the development of three-dimensional cadastres, as well as standard models, such as the ISO standard Land Administration Domain Model, for including utilities in land administration.

Keywords: utilities; utility registration; land administration; 3D cadastre; Scopus database; bibliometric analysis



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1. Introduction

Utilities such as electricity, water, heat, oil, gas, sewage, and electronic communication are an integral part of daily life and economic activity for every modern society. The first utility networks can be traced all the way back to the Bronze Age and the first permanent settlements. Since then, number of utility networks has only grown. At present, with rapid urbanisation and industrialisation, proper utility and land administration has become more important than ever [1]. The first utility networks that were built were rarely registered and, in many cases, not registered at all [2]. Non-existent or insufficient data on utilities can also lead to damage and accidents during various excavation works. Therefore, the Pipeline and Hazardous Materials Safety Administration of United States of America reported almost USD 12 billion in damages over a period of 20 years [3]. For internal technical purposes, utility companies have operating cadastres with data on the utility infrastructure that they manage. When it comes to security, this information from the operating cadastres must be shared with all concerned parties.

Utility networks were initially built and owned by states or state-owned companies. As these networks were usually built on state-owned parcels, the legal relations between the utility infrastructure and the land parcels that they crossed were of little concern. At present, utility networks are owned by either private or public companies that are responsible for the delivery of these essential services to homes, businesses, and other facilities. Therefore, there is an additional need to register the legal features of utilities, as well as the legal interests of the utilities and the land parcels that the utilities cross [2].

Land administration is an operational component of the land management paradigm. Land administration is the process of recording and disseminating information about

interests (rights, restrictions, and responsibilities), land value, land use and entities associated with the land, which include underground and overground objects such as utilities. Consequently, it is beneficial to include utilities in land administration systems [4].

Approaches to utility administration vary significantly from jurisdiction to jurisdiction. Some jurisdictions record utility networks as separate entities in their land administration systems, others have separate utility cadastres, and some record only easements on cadastral parcels. During FIG 3D Cadastre workshops, several questionnaire surveys regarding the status of a 3D cadastre in different jurisdictions were conducted [5–7]. The results showed that 30% of the jurisdictions registered utility networks in their land administration, with an additional 7% having separate utility cadastres for such a purpose. The results also showed that 24% of the jurisdictions registered only the easements, or tunnel spaces, of the utility networks in their land administration [8].

Two different approaches can also be recognised when it comes to utility administration. The first type is the authoritative approach, where utility cadastres are established with laws and regulations, and with utility managers, who are responsible by law for updating the central database. Such approaches are more prevalent in former eastern bloc countries, such as Croatia or Slovenia, who have dedicated utility cadastres for utility administration. The other, non-authoritative, approaches are more prevalent in the western countries, where utility managers maintain the data about their utilities in separate registers, while the jurisdictions, usually local administrative units, enable the sharing of information about utilities with concerned parties through call centres or other platforms [8]. Such approaches are found in the United States of America, Australia and Canada, as well as other western countries who have call centres. In these countries, excavators are obliged to contact a call centre before the excavation work begins. Soon after, utility managers that manage the utilities in the area forward the data about the locations of their utilities to the excavators or mark them on the ground where the excavation is to take place [9–11].

The Land Administration Domain Model (LADM) is an ISO standard and a conceptual scheme for modelling the legal relationships and interests on land, such as rights, restrictions, and responsibilities [12]. When it comes to utilities, modelling the physical features of utilities is outside the scope of LADM and is left to external classes. Notwithstanding, many jurisdictions include data about utilities in their LADM national profiles.

In this study, we analysed the research on public utilities registration in land administration. The aim of this study was to determine the interest in utility registration in both academia and industry, which indicates the real-world value of the topic. We aimed to determine whether the topic of utility registration is of global interest or only of interest in urbanised and highly developed countries, which generally have more utilities. Efficient utility model registration requires the development of a 3D cadastre. The aim of this research is therefore to find out how the topic of utility registration is aligned with research concerned with 3D land administration, such as 3D cadastre and LADM research, as well as how utility registration research is performing compared to cadastre and land administration research in general.

Therefore, this research aimed to answer the following questions:

- To what extent is the topic of 3D cadastres associated with research concerning public utility registration?
- To what extent is the topic of LADM associated with research concerning public utility registration?
- Which countries and institutions conduct the most research concerned with the topic of public utility registration?
- How does research concerned with public utility registration perform in relation to land administration research in general?
- What are the most important and influential publications related to the topic of public utility registration?
- To what extent is the industry included in the research related to the topic of public utility registration?

In Section 2, the materials and methods used for this research will be described in detail. In Section 3, the results of bibliometric analyses on the publications' performance over the years, countries and institutions that are involved, keywords, and related topics are presented and discussed. Finally, in Section 4, a conclusion is provided and answers to the research questions are summarized.

2. Materials and Methods

Publications such as articles, conference papers, book chapters, and other types of publications concerned with the topic of utilities and land administrations were the materials used for this research. The publications were obtained from the Scopus database. Scopus is an abstract and citation database with more than 1.8 billion cited references from more than 7000 publishers dating back to 1970 [13]. Publications were searched by title, abstracts and keywords using the Scopus search engine. The search with the query 'land administration' or 'cadastre' yielded 4092 publications, of which 508 publications also contained the keyword 'utilities' or 'infrastructure'. The final search thus yielded a total of 508 publications. The search was conducted in March 2023 with no time limit to cover all available research on the topic. The results contained publications from 1977 to 2023.

The words utility and infrastructure have been used to describe public utilities and infrastructure, such as water or electricity networks. However, the term infrastructure could be used to describe any resource needed for certain activities, including personnel, buildings, and equipment. It could also describe the underlying foundation or basic framework, such as data or spatial infrastructure, used in many of the resulting publications. Similarly, the term utility described something that was fit for a particular purpose or something that was useful or designed for general use. Therefore, the resulting publications were further filtered through manual review. Publications that were concerned with data infrastructure in land administration, or other topics unrelated to utilities, were excluded from the results. After final filtering, the search resulted in 241 publications concerned with utilities in land administration. The citations, bibliographic information, abstracts and keywords of these publications were collected. In particular, citation information, such as the authors, title of the publication, year, title of the source, citation count, and type of publication, were collected. Bibliographic information, such as affiliation, publisher, correspondence address, and editors, was also collected.

As shown in Figure 1, a bibliometric performance analysis and a scientific mapping analysis were used for this research. A bibliometric analysis is a quantitative study of publications based on statistical methods that provides a systematic review of the research conducted on a particular topic [14]. This analysis provides information about the performance and contributions to scientific research. The selected publications were analysed according to the type of publication, i.e., article, conference paper, book chapter, conference revision, review, editorial, note, or short survey. The second analysis looked at the performance of the publications over the years, i.e., the number of documents published each year. This analysis helps us to answer the research question about the performance of utility registration research compared to land administration research in general. Therefore, the performance throughout the years was also compared with the performance of the publications selected with the search query 'cadastre' or 'land administration' to show the performance of research on the utilities in land administration with respect to that of research related to the topic of land administration in general. Journals that published the maximum number of articles on the topic of utilities in land administration were reviewed. The most-cited publications were also studied to review the most influential publications on the topic of utilities in land administration, thus answering the fifth research question. To show where the most research was conducted, countries and institutions with the maximum number of publications were analysed to answer the research question regarding which countries and institutions are most productive on the topic of utility registration. Institutions were also divided into two categories, namely universities and other institutions, such as government institutions and public and private companies, to answer the

research question regarding the extent to which industry is involved in research on utility registration. A scientific mapping analysis was used to show the collaboration between institutions, the co-occurrence of countries in the publications, and the use of keywords in the publications, which revealed the research trends and the associated topics. The keyword analysis helps us answer the research question about the alignment of 3D cadastre and LADM-related research with research that deals with utility registration.

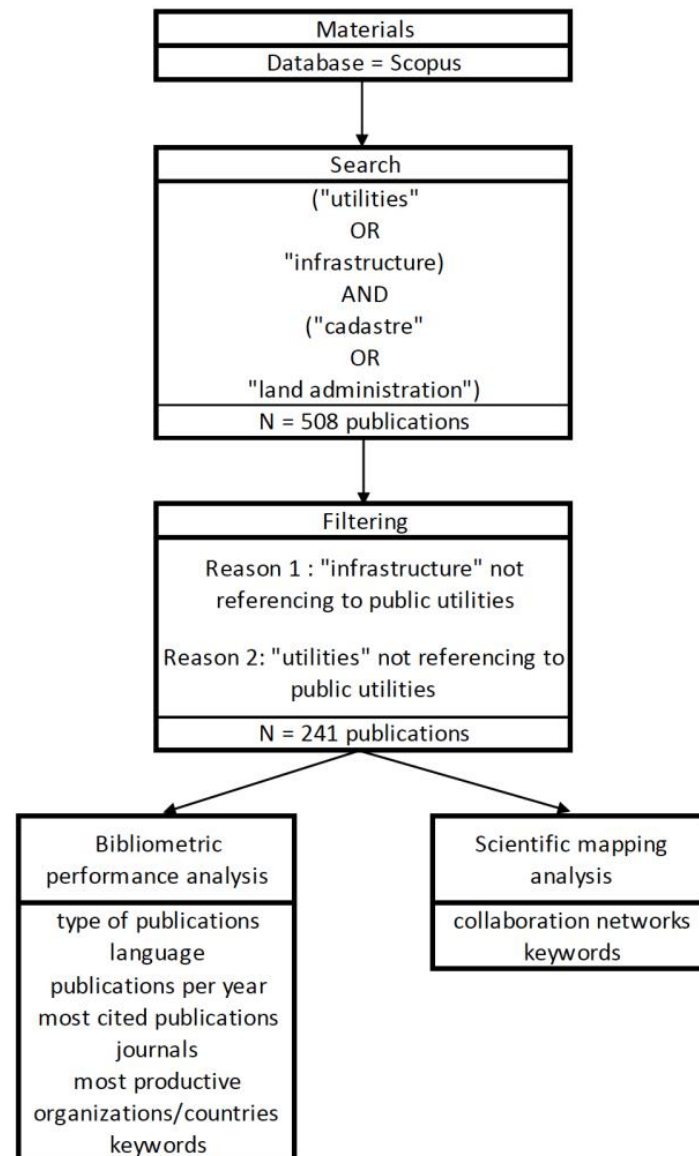


Figure 1. Research methodology (own compilation).

The scientific mapping analysis was conducted with the VOSviewer software [15], a tool for constructing and visualising bibliometric networks.

3. Results and Discussion

In total, information about 241 publications was included in the research. As shown in Figure 2, 138 journal articles (57.3%), 70 conference papers (29.0%), 14 book chapters (5.8%), 9 conference reviews (3.7%), 6 reviews (2.5%), 2 editorials (0.8%), 1 note (0.4%), and 1 short survey (approximately 0.4%) of all of the publications were included in this study.

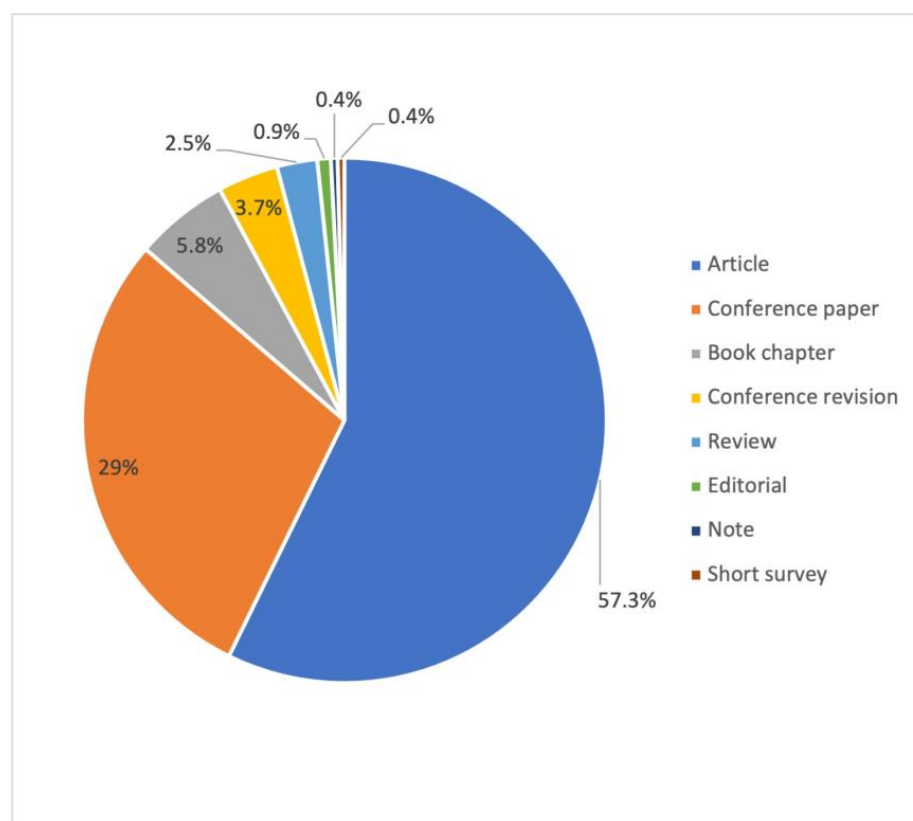


Figure 2. Types of utility registration publications (own compilation).

The total number of articles, as well as that of all of other publications related to the topic of utilities in land administration, was smaller than that of other topics related to land administration, with a search with the keyword ‘building’, together with the keyword ‘land administration’ or ‘cadastre’, returning 653 publications in total. In contrast, a search with the keyword ‘land administration’ or ‘cadastre’ returned 4094 publications. In a comparison with other search results, we observed a higher percentage of conference papers compared to publications on the topics of ‘land administration’ or ‘cadastre’, with 20.2%, and ‘land administration domain model’, with 24.1% of the publications being conference papers.

When it came to languages, as shown in Figure 3, most of the publications were in English, with 206 publications or 83.7% of all the publications. Slovenian was the second most frequent language, with 10 publications, or 4.1%. Six publications, or 2.4%, were written in German. Five publications, or 2.0%, were written in Croatian. Three publications (1.2%) were written in Dutch, Hungarian, Russian, and Spanish, and Chinese, French, Italian, Japanese, Portuguese, Serbian, and Ukrainian were used in one publication each. Publications could have more than one original language; therefore, the sum of all publications per language could exceed the total number of publications. Most of the publications written in languages other than English were concerned with a specific issue in certain countries. This showed that the topic of public utilities in land administration was universal and of international interest. These results also correlated with the results retrieved using the search query ‘cadastre’ or ‘land administration’, with English being the predominant language in the publications again (70%), and German, Slovenian, French, Hungarian, Spanish, Russian, Chinese, Dutch, and Croatian being the 10 most popular original languages besides English in the considered publications.

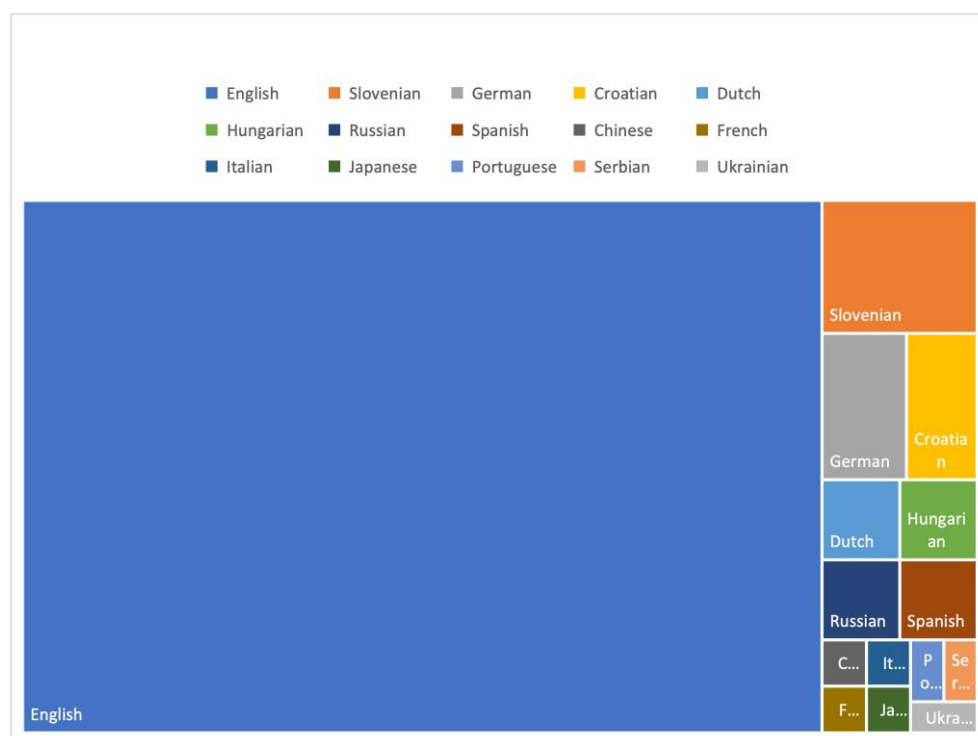


Figure 3. Number of publications per original language (own compilation).

Each publication was also a part of at least one research subject area, so the sum of all of the publications per research subject area exceeded the total number of selected publications. To be specific, 105 publications belonged to social sciences; 101 publications to earth and planetary sciences; 75 to environmental science; 43 to engineering; 42 to computer science; 26 to agricultural and biological science; 15 to energy sciences; 12 to physics and astronomy; 9 to business, management, and accounting; 7 to economics, econometrics, and finance; 7 to materials science; 5 to decision sciences; 4 to arts and humanities; 4 to mathematics; 3 to biochemistry, genetics, and molecular biology; and 3 to chemistry. One publication belonged to a multidisciplinary subject area.

3.1. Publications per Year

The first publication was ‘Control networks with wall monumentation: A basis for integrated survey systems in urban areas’, from 1977, which discussed options for control networks with wall monumentation for integrated information systems in urban environments for urban topography, infrastructure, and land cadastre. As shown in Figure 4, the number of publications per year has increased. It was observed that until 2003, publications on the topic of utilities in land administration were published sporadically, with several years not containing any publication. A significant increase in research conducted on the topic was observed from 2003, particularly after 2010. Therefore, 89.6% of the publications were released from 2003 onwards, and 78.4% of all of the publications were released from 2010 onwards.

Table 1 shows the number of publications for each year, with the second column representing the number of publications per year selected in this research, i.e., publications on the utilities in land administration, and the third column representing the number of publications per year on the topic of land administration or cadastre in general. In the final column, the share of publications on the utilities in land administration is presented.

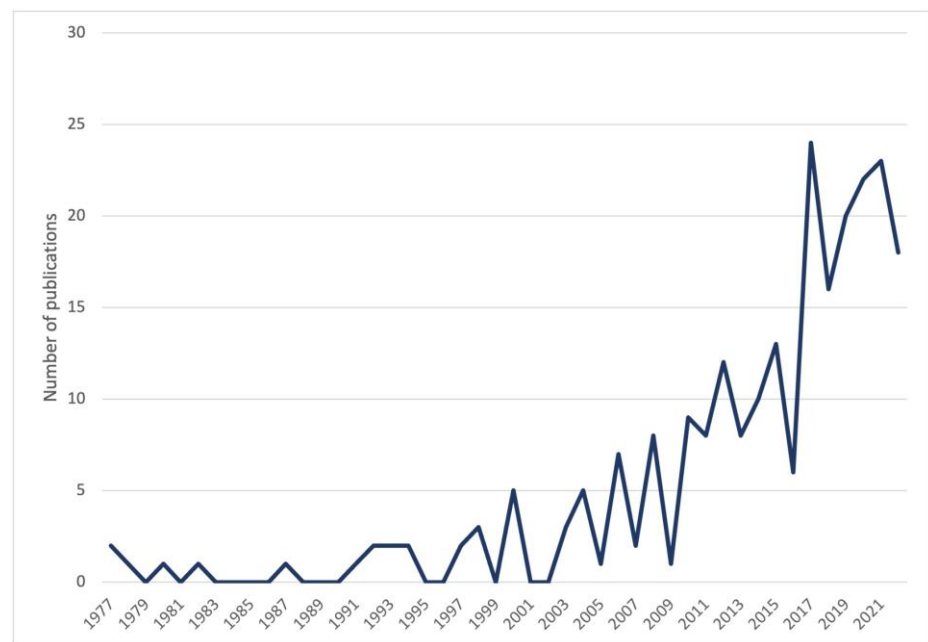


Figure 4. Publications per year (own compilation).

Table 1. Number of publications for each year, starting from the year 1977.

Year	Publications on Utilities in Land Administration (A) ¹	Publications on Land Administration (B) ²	Percentage (A/B%)
1977	2	8	25%
1978	1	10	10%
1979	-	11	-
1980	1	13	7.7%
1981	-	9	-
1982	1	31	3.2%
1983	-	20	-
1984	-	17	-
1985	-	19	-
1986	-	16	-
1987	1	16	6.3%
1988	-	21	-
1989	-	16	-
1990	-	21	-
1991	1	22	4.5%
1992	2	21	9.5%
1993	2	21	9.5%
1994	2	25	8%
1995	-	33	-
1996	-	24	-
1997	2	34	5.9%
1998	3	35	8.6%
1999	-	35	-
2000	5	38	13.2%
2001	-	54	-
2002	-	48	-
2003	3	71	4.2%
2004	5	73	6.8%

Table 1. Cont.

Year	Publications on Utilities in Land Administration (A) ¹	Publications on Land Administration (B) ²	Percentage (A/B%)
2005	1	61	1.6%
2006	7	122	5.7%
2007	2	104	1.9%
2008	8	120	6.7%
2009	1	110	0.9%
2010	9	143	6.3%
2011	8	149	5.4%
2012	12	140	8.6%
2013	8	186	4.3%
2014	10	161	6.2%
2015	13	238	5.5%
2016	6	175	3.4%
2017	24	248	9.7%
2018	16	238	6.7%
2019	20	268	7.5%
2020	22	272	8.1%
2021	23	298	7.7%
2022	18	224	8%

¹ Number of publications included in this research. ² Number of publications obtained for the search query 'land administration' or 'cadastre'.

Since the significant rise in 2010, the share of publications included in this bibliometric research was 6.9% of the publications that included 'land administration' or 'cadastre' in their titles, abstracts, or keywords. A slight growth can be observed as well, with 2022 ending in an 8% share of the publications.

In total, 241 publications were obtained from the Scopus database using the search strategy presented in this paper. Therefore, the total number of research publications on the topic of public utilities in land administration was rather low compared to those on other topics related to land administration and cadastre, with 4092 publications in total. The results of the performance analysis of the publications through the years showed that public utilities have continued to be an interesting and growing topic within land administration and cadastre research. Since the first paper on public utilities in land administration was published in 1977, the scientific production on this topic was sporadic until 2003. After 2003, the growth in research on public utilities in land administration matched the growth in research on land administration in general.

3.2. Journals

As shown in Table 2, out of the 138 articles in all, most (19 articles) were published in Land Use Policy. Land Use Policy is an interdisciplinary journal published by Elsevier concerned with issues in geography, agriculture, forestry, irrigation, environmental conservation, housing, urban development, and transport. In Geodetski Vestnik, which is an open access journal published by the Association of Surveyors of Slovenia, there were seven publications; the same holds true for the ISPRS International Journal of Geo Information, an open access journal of the International Society for Photogrammetry and Remote Sensing published by MDPI. In both Computers Environment and Urban Systems, which is another journal published by Elsevier, and Remote Sensing, a journal published by MDPI, there were six publications. Five publications were found in Survey Review, which is concerned with research on positioning, measurement, surveying, cadastre, and land management. Four publications were published in both Land and Geo Informations Systeme. Land is another open access journal published by MDPI and concerned with land system science, while Geo Informations Systeme is a German journal concerned with geography, planning,

and development, published by Wichmann. The remaining 80 publications were published in 69 different journals.

Table 2. Journals with most published articles.

Rank	Journal Name	Number of Publications
1	Land Use Policy	19 (13.8%)
2	Geodetski Vestnik	7 (5.1%)
3	ISPRS International Journal of Geo Information	7 (5.1%)
4	Computers Environment and Urban Systems	6 (4.3%)
5	Remote Sensing	6 (4.3%)
6	Survey Review	5 (3.6%)
7	Geo Informations Systeme	4 (2.9%)
8	Land	4 (2.9%)
9	Other journals (69 journals)	80 (58.0%)

The eight most popular journals, which accounted for 10% of all of the journals with at least one article published on the researched topic, published 42% of the total number of articles on the topic of utilities in land administration. The publications retrieved with the search query ‘cadastre’ or ‘land administration’ showed similar results, with Land Use Policy as the most popular journal. Survey Review, Land, Computers Environment and Urban Systems, Geodetski Vestnik, and ISPRS International Journal of Geo Information were again among the eight most popular journals on these topics, which showed that the research topic of utilities in land administration followed the trends of the land administration topic in general.

3.3. Most-Cited Publications

As shown in Table 3, the most cited publication was ‘The Land Administration Domain Model’ by Lemmen van Oosterom and Bennet, with 164 citations in total. This paper presented the LADM standard as published by ISO and was cited by almost all the LADM-related research publications [16]. This paper was not primarily concerned with public utilities but described the LADM standard in general. Regarding utilities, the LADM is primarily concerned with the legal spaces of utility networks, such as the easement or superficie spaces. The legal space of utility networks usually includes the space of physical utilities and some buffer area around physical objects. Therefore, the modelling of physical features is left to external classes. The second-most cited paper was ‘The core cadastral domain model’, with 89 citations. This paper presented the core cadastral domain model which, in addition classes for modelling parcels, persons, and rights, includes classes for modelling easements, right of way, legal spaces of utility networks, and other objects. This paper could be considered a predecessor to the previously mentioned paper and LADM [17]. Furthermore, this paper was not primarily concerned with public utilities but addressed the modelling of all features that were registered in a cadastre. The third most-cited paper was ‘Smart microgrids as a solution for rural electrification: Ensuring long-term sustainability through cadastre and business models’, which emphasised the importance of cadastral data for building microgrids for rural electrification [18]. The fourth most-cited paper was ‘Research and development in 3D cadastres’, which reviewed the research and development in 3D cadastres, including infrastructure registration, which could not be adequately registered in 2D [19]. The fifth most-cited paper was ‘Towards integration of 3D legal and physical objects in cadastral data models’, which proposed a 3D cadastral data model as an improvement to the current cadastral data models [20].

Table 3. Most-cited publications.

Rank	Publication Title	Authors	Number of Citations
1	The Land Administration Domain Model	Lemmen, C., van Oosterom, P., Bennett, R.	164
2	The core cadastral domain model	van Oosterom, P., Lemmen, C., Ingvarsson, T., (. . .), Stoter, J., Zevenbergen, J.	89
3	Smart microgrids as a solution for rural electrification: Ensuring long-term sustainability through cadastre and business models	Ubilla, K., Jimenez-Estevez, G.A., Hernandez, R., (. . .), Severino, B., Palma-Behnke, R.	81
4	Research and development in 3D cadastres	Van Oosterom, P.	74
5	Towards integration of 3D legal and physical objects in cadastral data models	Aien, A., Kalantari, M., Rajabifard, A., Williamson, I., Wallace, J.	66
6	4D cadastres: First analysis of legal, organizational, and technical impact-With a case study on utility networks	Doner, F., Thompson, R., Stoter, J., (. . .), van Oosterom, P., Zlatanova, S.	59
7	Towards a 3D cadastre: Where do cadastral needs and technical possibilities meet?	Stoter, J., Salzmann, M.	59
8	Road Mapping: Megaproject and Land Grabs in the Northern Guatemalan Lowlands	Grandia, L.	55
9	Solutions for 4D cadastre—with a case study on utility networks	Doner, F., Thompson, R., Stoter, J., (. . .), van Oosterom, P., Zlatanova, S.	45
10	Transition from 2D to 3D real property cadastre: The case of the Slovenian cadastre	Drobež, P., Fras, M.K., Ferlan, M., Lisec, A.	37

The sixth most-cited paper was ‘4D cadastres: First analysis of legal, organisational, and technical impact-With a case study on utility networks’, which discussed the approaches to utility registration in three different jurisdictions, namely the Netherlands, Turkey, and Queensland, Australia [21]. The seventh most-cited paper was ‘Towards a 3D cadastre: Where do cadastral needs and technical possibilities meet?’, which described the cadastral needs in The Netherlands, as well as the technical possibilities for the registration of physical 3D objects, such as above- and underground infrastructure [22]. The eighth most-cited paper was ‘Road Mapping: Megaproject and Land Grabs in the Northern Guatemalan Lowlands’, which reviewed the mega-infrastructure projects in the Americas and the challenges that such projects created for land administration and land management [23]. The ninth most-cited paper was ‘Solutions for 4D cadastre—with a case study on utility networks’, which discussed the possibilities for the registration of the legal spaces of utility networks in 4D cadastres in three different jurisdictions, namely the Netherlands, Turkey, and Queensland, Australia [24]. The tenth most-cited paper was ‘Transition from 2D to 3D real property cadastre: The case of the Slovenian cadastre’, which reviewed the possibilities for a multi-purpose 3D real property cadastre in Slovenia [25].

By reviewing the most influential papers on public utilities in land administration, we observed that the two most-cited papers focused primarily on the topic of land administration models, while public utilities were studied as one of the components of land administration. Most of the other influential papers researched the development of 3D cadastres, which indicates 3D cadastres as a basis for utility registration.

3.4. Countries

In Figure 5, most of the countries involved in the research on the topics of utilities in land administration are shown. The country included in the most papers was Australia, with 28 publications, or 11.6%. The second country was the Netherlands, with 19 publications, or 7.9%, followed by Greece and Slovenia, with 14 publications each, or 5.8% each. Three more countries were included in 10 or more publications, with Malaysia included in 12, or 5%, and Croatia and Italy included in 10 publications each, or 4.1% each. Romania and Switzerland were included in 9 publications each, or 3.7% each; Germany, Poland, and Singapore in 8 publications each, or 3.3% each; Turkey and the United States

in 7 publications each, or 2.9% each; China and the United Kingdom in 6 publications each, or 2.5% each; and Brazil, Ghana, Indonesia, Russia, and Ukraine in 5 publications each, or 2.1% each. Another 35 countries were included in fewer than 5 publications each, while 29 publications were undefined. If we compared these with the search results on ‘cadastre’ or ‘land administration’, the Netherlands and Australia were again the most involved countries in the publications, with 324 and 270 publications, or 7.9% and 6.6%, respectively.

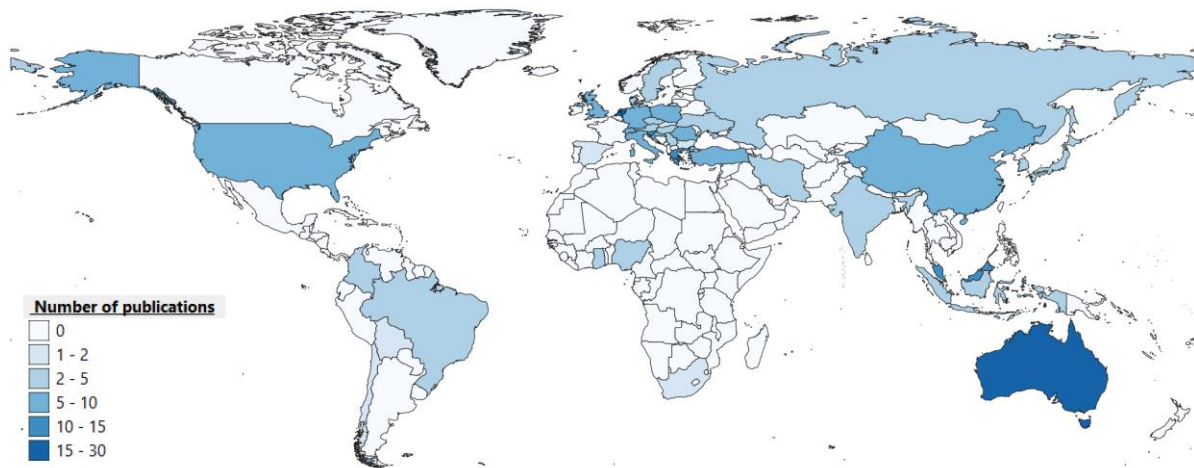


Figure 5. Countries involved in publications (own compilation).

Therefore, interest in this research topic could be observed across the globe, with Africa lagging behind the rest of the world. This also pointed to the known issues of underdeveloped public utility networks, as well as a lower level of urbanisation on the continent. When compared with the publications obtained with the search query ‘cadastre’ or ‘land administration’, Australia and the Netherlands were again the most productive countries. Table 4 shows the 10 most productive countries on the topic of utilities in land administration, with the number of publications on the topic, as well as the number of publications published on the topic of land administration in general. Note that when it came to the share of research conducted on the topic of utilities in land administration, Singapore, a highly developed city state, had the highest share of publications in land administration that were concerned with utilities, with 50% publications including utilities.

Table 4. Number of publications for each year, starting from the year 1977.

Rank	Country	Publications on Utilities in Land Administration (A) ¹	Publications on Land Administration (B) ²	Percentage (A/B%)
1	Australia	28	270	10.4%
2	Netherlands	19	324	5.9%
3	Greece	14	87	16.1%
-	Slovenia	14	112	12.5%
5	Malaysia	12	72	16.7%
6	Croatia	10	97	10.3%
-	Italy	10	136	7.4%
8	Romania	9	102	8.8%
-	Switzerland	9	56	16.1%
10	Germany	8	218	3.7%
-	Poland	8	159	5.0%
-	Singapore	8	16	50.0%

¹ Number of publications included in this research. ² Number of publications obtained for search query ‘land administration’ or ‘cadastre’.

In Figure 6, the collaboration between countries, obtained using the VOSViewer software, is shown. The size of the circle shows the contribution of each country, with a larger circle representing a higher contribution to the research. Links between circles indicate the collaboration between countries, with the thickness of lines representing a higher level of collaboration between the connected countries. The countries are also separated by colour in clusters, representing different collaborative groups. The largest collaborative group consisted of the Netherlands, Australia, and Greece. In the same cluster, we observed India and Romania, but with a significantly lower collaboration. Almost all of the other countries referenced the research conducted by this collaboration group. Several other clusters can be observed: Turkey, Germany, South Korea, Poland, Serbia, and Czechia are shown in red as close to the largest collaborative group, with Turkey having the closest collaboration with said group. Croatia and Slovenia, together with Ukraine, are shown in light blue; Sweden, Denmark, Ghana, the United Kingdom, and Italy are shown in green. Another two clusters can be observed, with Brazil, Singapore, China, and the United States shown in purple, and Nigeria, Malaysia, Indonesia, Switzerland and Iran shown in yellow.

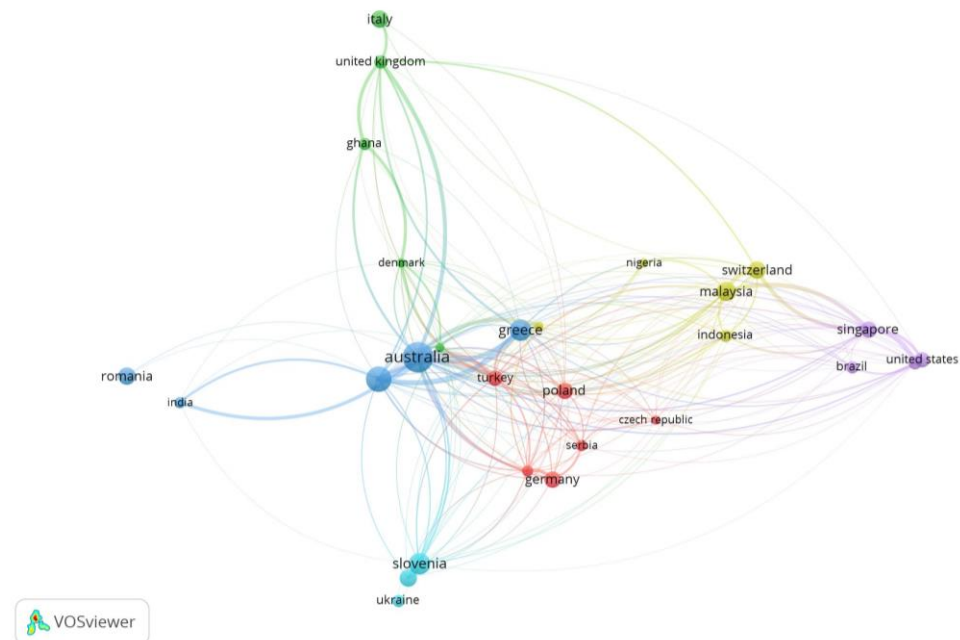


Figure 6. Collaboration network of countries (own compilation).

The similar largest collaborative group, with the Netherlands, Australia, and Greece, was observed in LADM-related research, with Turkey as another highly included and connected country in both research topics [26].

The results of the analysis of scientific productions per country and the country collaboration network revealed that the topic of public utilities in land administration was of global interest, with more developed and urbanised countries conducting more research on the topic. This indicated that such countries also had more developed public utility networks, as well as more complex urban spaces with more complex constructions, buildings, and public utility networks, and with more challenges related to the management and administration of public utilities. The collaboration analysis showed that the largest research group was similar to the largest research group on the topic of LADM and land administration in general, which indicated that the issue of public utilities in land administration is being recognised by the most influential researchers. The results also showed that countries with an authoritative approach and national utility cadastres, such as Croatia and Slovenia, were more likely to include utilities in their research on land administration.

3.5. Institutions

As shown in Table 5, the most productive institutions were the University of Melbourne, with 19 publications, or 7.9%, followed by the Technical University of Malaysia, with 12 publications, or 5%. The National Technical University of Athens and Delft University of Technology had 10 publications each, or 4.1% of all the publications. ETH Zurich, University of Ljubljana, and Singapore ETH Centre had 7 publications each, or 2.9% each, while the University of Zagreb and University of Twente had 6 publications each, or 2.5%. Additionally, 3 institutions had 5 publications each, 3 institutions had 4 publications each, 11 institutions had 3 publications each, 24 institutions had 2 publications each, while another 110 institutions participated in one publication each. Several institutions collaborated on the same research, resulting in publication. Therefore, the sum of all of the publications per institution was larger than the total number of all publications.

Table 5. Most productive institutions.

Rank	Institution Name	Number of Publications
1	University of Melbourne	19 (7.9%)
2	Universiti Teknologi Malaysia	12 (5.0%)
3	National Technical University of Athens	10 (4.1%)
4	Delft University of Technology	10 (4.1%)
5	ETH Zurich	7 (2.9%)
6	University of Ljubljana	7 (2.9%)
7	Singapore ETH Centre	7 (2.9%)
8	University of Zagreb	6 (2.5%)
9	University of Twente	6 (2.5%)
10	151 institutions	145 (60.2%)

When compared with publications obtained using the search query ‘cadastre’ or ‘land administration’, the same universities could be observed as the most productive in research, with the University of Twente as the most productive, with 143 publications, or 3.5%, followed by the University of Melbourne, with 130 publications, or 3.2%, and Delft University of Technology, with 101 publications, or 2.5%. The University of Technology Malaysia, National Technical University of Athens, University of Ljubljana, and University of Zagreb were all listed as the 10 most productive institutions on the topic of land administration in general. Unlike the results for the most productive institutions in terms of research on the topic of utilities in land administration, the production of publications per institution was more evenly distributed.

Universities were the institutions with the most publications, but certain government administrations, as well as companies, were involved in some publications, such as State Geodetic Administrations of Croatia and Slovenia, Cadastre of Netherlands, Deutsche Telekom, and Osijek Vodovod. These public and private institutions and companies collaborated in 75 publications, or 31.1%. This showed that the research topic of utilities in land administration was important to both the government and industry.

The analysis of the most productive institutions revealed that universities were the most-involved institutions in research, which was expected, but some government institutions and utility companies were involved in almost a third of the publications, which showed that public utilities’ registration is a valuable topic in industry and this sector also had a high level of interest in the topic.

3.6. Keywords

As shown in Table 6, the most used keyword was ‘cadastre’, with 58 occurrences, followed by the keywords ‘GIS’, with 31 occurrences, and ‘3d cadastre’, with 30 occurrences; these were followed by ‘land administration’, with 23 occurrences, and ‘urban planning’, with 21 occurrences. The sixth most used keywords were ‘land management’ and ‘land use’, with 20 occurrences each. The eighth most used keyword was ‘mapping’, with 18 oc-

currences, followed by ‘geographic information systems’ and LADM, with 17 occurrences each. Some keywords were classified as separate in the Scopus classification but had the same meaning. For instance, GIS was the abbreviation for Geographic Information System and LADM was the abbreviation for Land Administration Domain Model, which had seven more occurrences. Three-dimensional cadastre also had two variations, with the keyword ‘3d Cadastre’ having four more occurrences. Apart from the keywords referencing 3D cadastre, we observed several other keywords that included the abbreviation ‘3D’ and, as such, showed the importance of the third dimension for public utilities registration. Such keywords were ‘3D modelling’, with 10 occurrences; ‘3D Land Administration’ and ‘3D Property’, with 5 occurrences each; ‘3D Model’ and ‘3d Cadastre’, with 4 occurrences each; and ‘3-d modelling’, ‘3D Data’, ‘3D Data Model’, ‘3D Data Modelling’, and ‘3D GIS’, with 3 occurrences each.

Table 6. Most used keywords.

Rank	Keyword	Occurrence
1	Cadastre	58
2	GIS	31
3	3D cadastre	31
4	Land administration	23
5	Urban planning	21
6	Land management	20
7	Land use	20
8	mapping	18
9	Geographic Information Systems	17
10	LADM	17

The time periods for each of the 10 most used keywords were analysed. For this purpose, keywords that had the same meaning were grouped together, such as ‘LADM’ and ‘Land Administration Domain Model’. Therefore, Figure 7 shows the time periods for the selected keywords, with the keywords ‘Cadastre’ and ‘Urban Planning’ having the longest timespans of 43 and 45 years, respectively. Other keywords were introduced after 1995, with the last two introduced keywords being ‘3D Cadastre’ in the year 2003 and ‘LADM’ in the year 2013. Note that, since 2013, when the last keyword was introduced, the most used keywords were ‘Cadastre’ and ‘3D Cadastre’, both being used on 29 occasions, with ‘LADM’ being the third most used keyword, with 21 occurrences. This indicates the importance of the 3D cadastre and LADM research for public utilities registration.

As shown in Figure 8, 164 different keywords were used at least three times. On the basis of these keywords, a co-occurrence network was created using the VOSviewer software. The circles represent the nodes of the network representing keywords, with the size of the circle representing the number of occurrences of a certain keyword. Therefore, keywords with a higher occurrence number are represented by larger circles. The lines denote the links between the network and represent the co-occurrence between keywords, i.e., which keywords were mentioned together in the same publication. The line thickness then represents the frequency of a certain co-occurrence. VOSviewer automatically classified the keywords into four clusters, with the red cluster containing “3d cadastre” keyword together with “3d land administration”, “utility cadastre”, as well as the keyword “ladm” and some other keywords representing research topics related to 3D land administration.

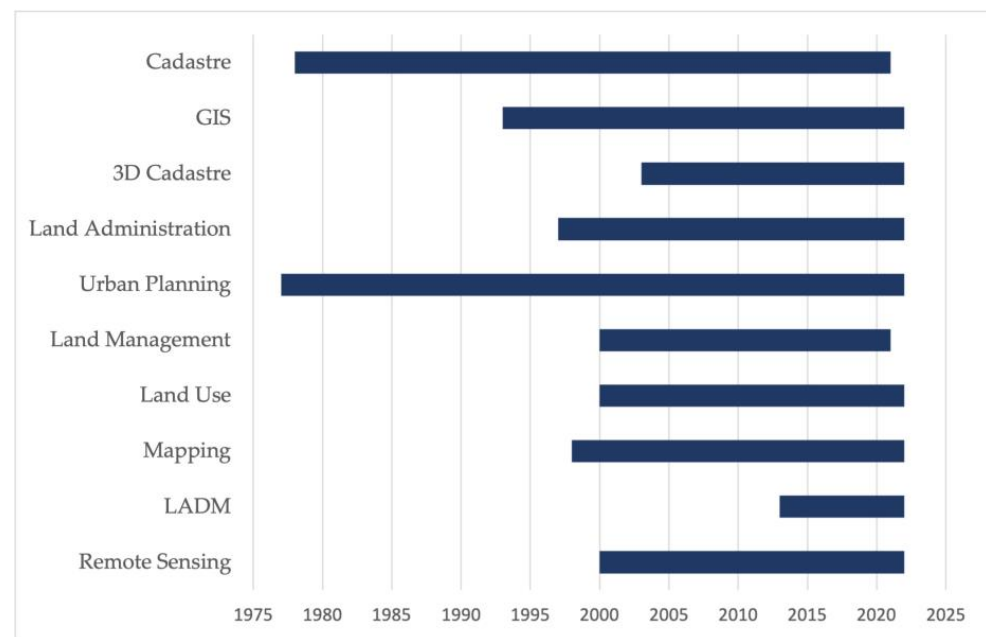


Figure 7. Time period of used keywords (own compilation).

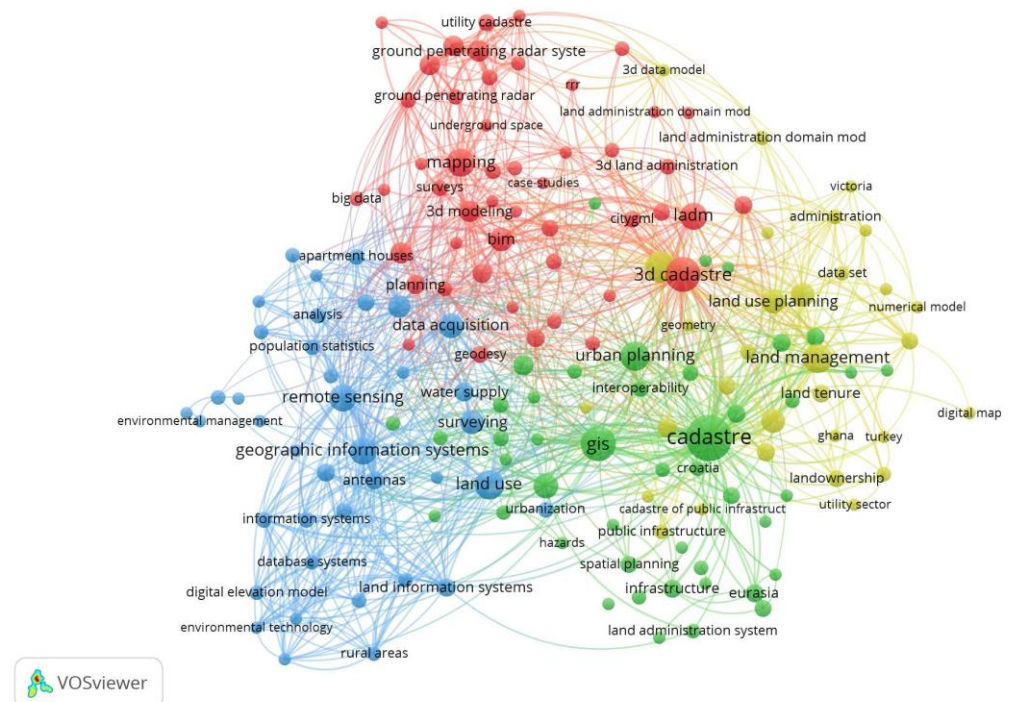


Figure 8. Most used keywords (own compilation).

Other related clusters are shown in the yellow, green and blue clusters, with the yellow cluster containing “land administration” and “land management” keywords. The green cluster contains the keywords “urban planning”, “urban development”, “cadastre”, “gis”, etc. Finally, the blue cluster contains keywords such as “geographic information systems”, “remote sensing”, and “3d gis”. Even though the keywords were separated into four different clusters in VOSviewer, we observed that the separation between the keywords of different clusters was not significant. Instead, the keywords of different clusters were interchangeable and closely related.

The keyword analyses revealed that the research topic of utilities in land administration was closely related to the 3D cadastre research topic, as well as LADM. Many research

publications also contained the topic of ground-penetrating radars as the most popular technique for locating underground utilities. As in an urban environment, challenges with utilities are the most pronounced, and connection with topics on urban environments and urban planning could be observed as well.

The results of the keyword analysis also showed that the research topic of 3D cadastre was closely related to the public utilities registration research. In the last 10 years, '3D Cadastre' has been the most used keyword in publications on the topic of public utilities in land administration. As utility networks are often located over- or underground, and usually intersect a large number of land parcels, 2D land administration is not adequate for the appropriate registration of either physical or legal spaces of public utilities [27]. Therefore, research on the topic of 3D cadastre started as a solution to the challenges of the registration of complex objects in space, such as public utilities, complex constructions such as bridges, and complex buildings in 3D spaces [28]. To overcome the technical challenges of a 3D cadastre, the development of data models adequate for a 3D cadastre, as well as defining ways for a technical transition from a 2D to a 3D cadastre, were necessary steps [29]. Additionally, as a cadastre is a register of rights on land, the development of such technical capabilities for a 3D cadastre had to be accompanied by the development of institutional and legal frameworks of 3D property rights and cadastres [30,31].

Current cadastral approaches in many jurisdictions are still based on a 2D cadastral model, which is not sufficient for modern requirements and for the representation of the current legal and physical situations encountered in the real world [32]. A 3D cadastral model would improve such cadastral approaches in many jurisdictions, where cadastral models are not adequate for 3D legal and physical objects [20,22]. Different jurisdictions also have different legal, organisational, and technical approaches to cadastres and public utility registration [21,24]. Therefore, research on the technical, legal, and institutional challenges is crucial to successfully upgrade land administration from a 2D to the 3D concept, which could then enable public utility registration in land administration [33].

Research on the topic of legal and organisational challenges follows the growth in other topics concerned with 3D cadastres but is still not adequate in comparison [34]. Addressing the legal challenges in local laws and regulations, as well as the accuracy of public utility mapping and its compliance with the accuracy requested by the current land administration system, is an important step when establishing a 3D cadastre [35,36]. Research on the legal aspects shows the importance of a 3D cadastre for registering public law restrictions [37,38]. Public law restrictions, which, among others, include the restrictions intended for the protection and maintenance of public utilities, can be of an authoritative or informative character, and are usually managed by different organisations or institutions, as well as being recorded in separate databases. This shows the importance of standardising when it comes to the registration of public law restriction [39]. Furthermore, research on legal aspects shows the importance of 3D property units and their introduction to land administration, which could, in 3D cadastres, be owned or mortgaged directly [40,41].

Regarding the technical aspects of public utilities and 3D cadastres, research topics on 3D public utility mapping, as well as research on the whole workflow from data surveys to public utility data usage, is being conducted [42,43]. Digitalisation has improved the efficiency and transparency of land administration, which is why many jurisdictions are digitalising their land administration systems [44]. Therefore, the modelling of 3D physical objects and legal spaces is a highly researched topic, which often includes public utilities registration [45]. The results showed that popular modelling standards for 3D land administration and utilities include the OGC standard CityGML and the ISO standard LADM. CityGML, similar to LandInfra, and are concerned with the physical features of 3D objects, while LADM is concerned with the legal features of 3D objects [46]. Certain research efforts have been made to align these standards, such as the LandInfra and LADM standards [47]. Some of the research also shows that there is interest in including public utilities' registration in LADM through public utility data models based on LADM and by

extending the national LADM profiles, such as the research conducted for the use cases in Korea [48,49], Singapore [50,51], Brazil [52], Serbia [53], and Croatia [54].

The challenges of 3D space management are particularly visible in urban environments, where, in a limited amount of space, we encounter larger and more complex buildings and overground infrastructure, as well as underground buildings and infrastructure, such as tunnels, public utilities, or metro stations. Therefore, research topics on urban planning and urban environment are also closely linked to the research on public utilities' registration [55].

A significant number of publications have also studied various methods of mapping underground utilities. The most researched method included ground-penetrating radar technology, which is popular for mapping underground utility networks, and a method that uses radar pulses to create images of the subsurface of the ground [56–59].

4. Conclusions

Research on public utilities in land administration started relatively late. Until 2003, publications on the topic were sporadic, after which a significant rise in publications can be observed. This is not surprising, as the proper registration and mapping of utility networks has lagged behind their development, showing a lack of interest in this issue. The results showed that research on public utility registration is highly associated with the research on 3D cadastre and land administration, as well as with research on LADM. This was also expected, as the main challenge in public utility registration is the current 2D nature of land administration in many jurisdictions, either in their technical, legal, or institutional capabilities. Therefore, with the research and development of 3D land administration and cadastres, it is expected that public utility registration will become more included in multifunctional land administration systems. Including public utilities in land administration systems would also enable the registration of rights for public utilities, and with that, the registration of mortgages, which is challenging in many jurisdictions when using their current land administration systems. The importance of the standardisation of data modelling in land administration has also been recognised by the scientific community, with different jurisdictions exploring options for a public utilities' registration model based on LADM. This is also shown by the high number of publications concerned with LADM, with most cited publications dealing with the topics of utilities as part of 3D cadastre and LADM. The research topic of public utility registration has attracted worldwide interest. Research is being conducted, especially in highly urbanised and developed countries that have more challenges regarding efficient 3D land management, such as Singapore, the Republic of Korea and the Netherlands, as well as in countries with a more authoritative approach to public utility registration, such as Croatia or Serbia.

The bibliometric analysis that was carried out has shown the importance of 3D cadastre and LADM for future research on utility registration. The 3D cadastre is a necessary step on the way to utility registration, while the LADM is a standardised model for land administration in general, which could then also provide the basis for the utility registration model. The research that was conducted on the topic of public utility registration has covered both technical and legal issues. However, most research dealing with legal issues deals with restrictions on parcels, while research on the registration of rights for public utilities, such as property ownership, is limited. Therefore, future research on utility registration should also include the issue of utility registration as property.

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