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## Article

# 3D Property Research from a Legal Perspective Revisited

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**Abstract:** The concept of 3D cadastre is widespread internationally and part of many nations' legal infrastructure. Since the publication of a literature survey on 3D cadastre research by Paulsson and Paasch in 2013, there has been a considerable amount of research output and activities in regard to 3D cadastre, which led us to believe that a new investigation of 3D cadastre publications could be of interest. The aim of this study is to analyze the development in 3D cadastre research during the years 2012–2020, focusing on the legal perspective of 3D property. A classification was made into main groups, legal, technical, registration and organizational, also investigating the occurrence of sub-themes such as visualization, BIM and standardization. The results of other literature studies on 3D cadastre research were compared with the outcome of this study. The number of identified publications during the analyzed years was 530. The study showed that the number of publications on legal topics has increased, but in relation to the other groups is still rather low. The 3D cadastre research community could benefit from the inclusion of the legal perspective in publications from other main groups, along with an increased focus on international comparative studies.



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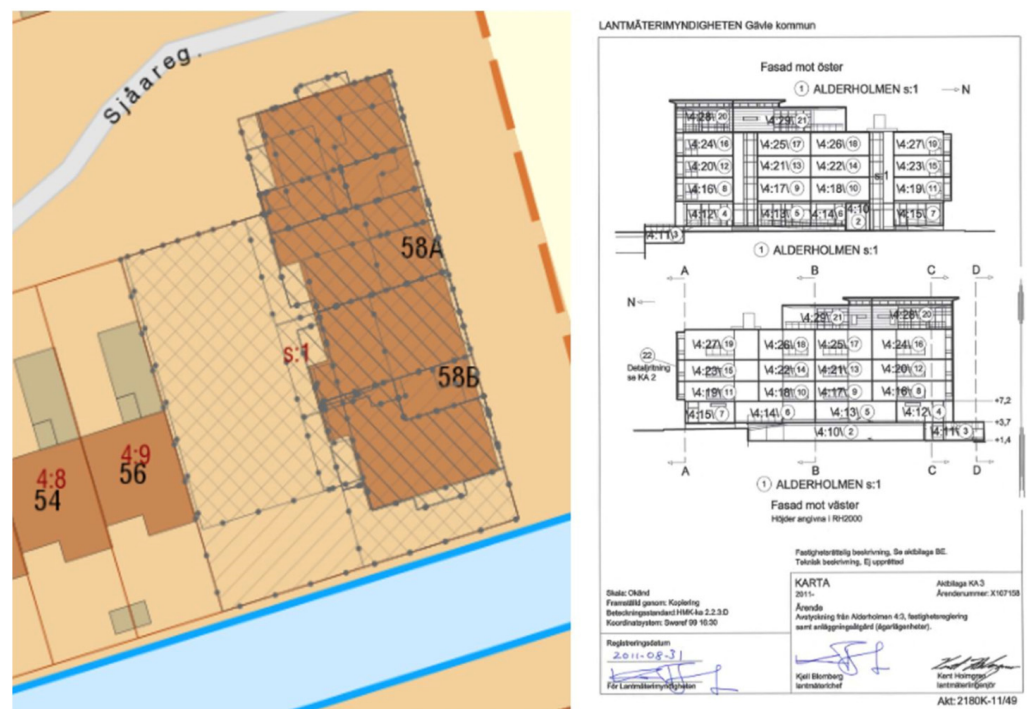
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**Keywords:** 3D property; 3D cadastre; classification; literature survey; real property strata; legislation

## 1. Introduction

Rights, restrictions and responsibilities (RRRs) regulating ownership of real property and other legal relations, such as easements/servitudes and other use rights, to land in three dimensions may be very complex legal structures, especially in city centers and other built up urban areas with intertwined land use. Examples are ownership and use rights to condominiums in high-rise buildings and infrastructure objects such as parking facilities, tunnels and pipe networks such as water, gas, electricity and Internet, under or above the earth's surface.

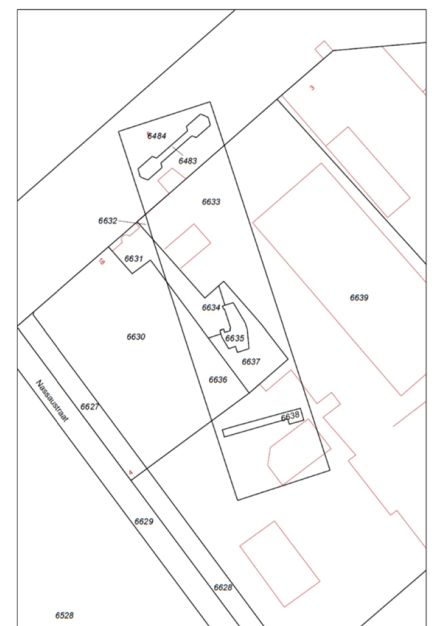
The concept of 3D cadastre and the registration of RRRs in three dimensions is widespread throughout the world and part of many nations' legal infrastructure. A multitude of legal and architectural solutions exist for creating RRRs in three dimensions for, e.g., apartment/condominium ownership as an alternative to, e.g., apartment lease, and other constructions subject to ownership or other use rights above or below ground, such as separate buildings and subway tunnels. See examples in Figures 1–3.



**Figure 1.** Illustration from the Swedish Digital Cadastral Index Map showing ownership apartments (left) and cadastral plans of the same properties (right) [1].

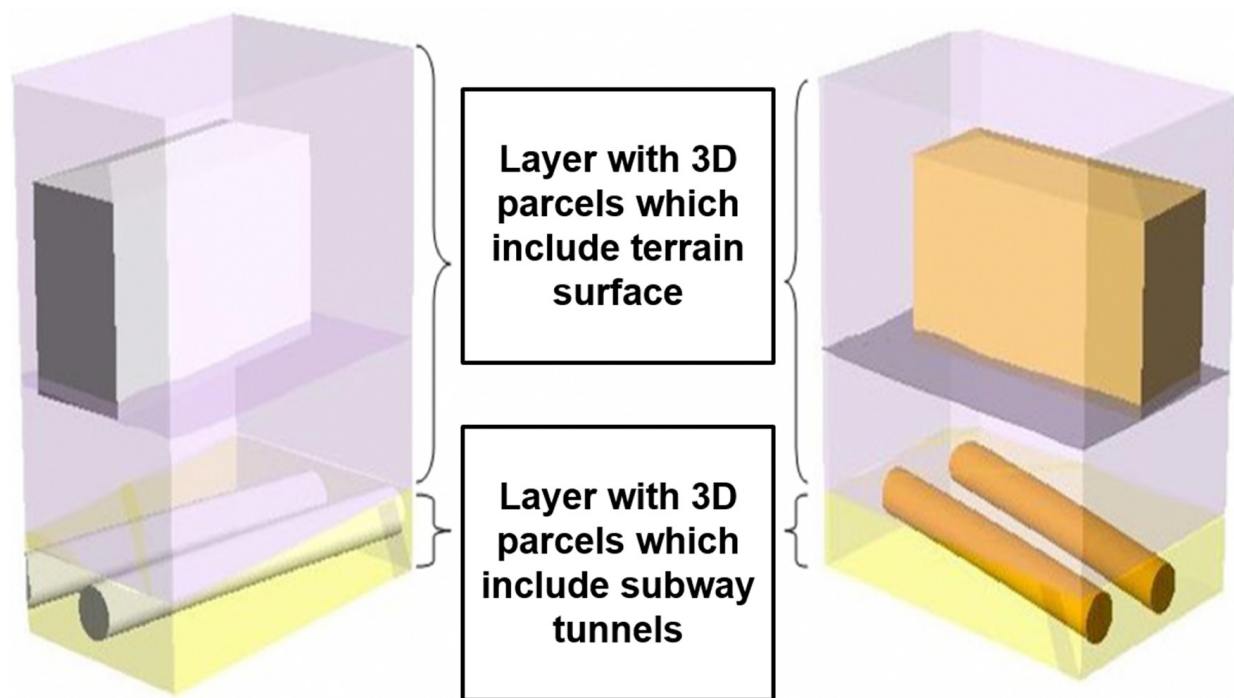


(a)



(b)

**Figure 2.** “The Bridge” building in Rotterdam, the Netherlands (a), being a separate real property above other properties and roads, shown on the Dutch Cadastral Index Map (b) [2]. Photo by F. Schouwenburg (Creative Commons-license).



**Figure 3.** Visualization of subway tunnels as individual cadastral parcels. Based on [3].

There has, especially during the last two decades, been published a number of research publications in the form of peer-review articles, conference proceedings including abstracts with abstract review, PhD theses, books and book chapters, and other publications, such as reports. Since the publication of the, we believe, first literature survey on 3D cadastre research in 2013 by Paulsson and Paasch [4] (hereafter referred to as the Paulsson and Paasch survey) and covering the years 2001–2011, there has been a considerable increase of research output and activities in regard to 3D cadastre. Examples are the Best Practices 3D Cadastres publication in 2018 [5] and a number of conferences and workshops, such as the International FIG (International Federation of Surveyors) workshops on 3D Cadastres in, among others, Shenzhen, China, in 2012 [6]; Dubai, United Arab Emirates, in 2014 [7]; Athens, Greece, in 2016 [8]; and Delft, the Netherlands, in 2018 [9].

This rapid development led us to believe that a new investigation of 3D cadastre covering 2012 and onwards focusing on legal topics could be of interest to the 3D cadastre research community. We also noticed that new topics have been introduced or gained increased focus in the studies in the 3D property domain during the last decade, such as visualization and standardization.

A large part of research on 3D real property has focused on more technical research, and less on legal and organizational issues, as noted also in the Paulsson and Paasch survey [4] and other literature surveys [10,11]. Implementation of new technical solutions requires an understanding of institutional matters, i.e., in what ways, according to what process, and by what financial means the solutions should be developed. They also must follow existing legislation, and new rules and regulations are often developed to accommodate these new solutions. Since the research is often focused on mostly technical aspects, such as data storage, and fails to address connected legal and organizational aspects, it would be beneficial to increase research on those aspects. Previous studies have identified the need for and recommended more research on legal aspects of 3D cadastre and noted the absence of common rules and terminology, see, e.g., position papers by Ploeger [12], Banut [13], and Paasch and Paulsson [14]. Therefore, this paper looks at the 3D property research from a legal perspective, in order to see whether this share has increased and what are the trends within this research topic.

The aim of this research is to analyze the focus and development in 3D cadastre research during the last decade. The purpose is twofold:

(1) To provide a follow-up study on the Paulsson and Paasch survey on 3D property research.

(2) To analyze and discuss the development of 3D property research since 2011, focusing on legal research topics.

Section 2 of the paper presents the materials and methods that have been used in the study. Section 3 provides a brief overview of some other literature studies of 3D cadastre that have been performed during the studied period. Section 4 presents the categories used for the classification, while Section 5 discusses legal aspects of 3D property. Section 6 presents the results of the classification, and Section 7 provides an analysis of the results, focusing on the research areas, contents of the legal research, as well as trends in 3D property research that could be identified. Discussion of the results, conclusions and suggestions for future research end the paper.

## 2. Materials and Methods

This study is made by analyzing the content of published research on 3D cadastre. The publications were identified through database searches. Examples are ScienceDirect, JSTOR and Scopus. In total, 46 databases were searched. The initial thought was that it would be possible to identify and classify publications by using the title and keywords, where available, as search parameters to describe the content. The initial searches used “3D cadastre” and “3D cadastral” as keywords, since “3D cadastre” had become an accepted term in the land management community, see, e.g., Oosterom [5] for descriptions of this type of real property. However, it soon became obvious that they were too general to be used as the basis for a detailed classification. This search was therefore refined using “3D cadastre”, “3D cadastral”, “3D cadaster”, “3D real property” and “property strata”, and combinations thereof, as keywords. The result was 530 publications on the topic of 3D cadastre, here used as a general term.

The publications showed a large variety in research approach, structure, academic level and scope. They range from doctoral theses that provide in-depth analyses of specific 3D cadastre topics to conference proceedings consisting of a few pages. They were all analyzed to achieve a classification into main groups, see below.

The principle in the Paulsson and Paasch survey [4], see below, to limit the study to English language publications is also applied to this study, since non-English publications are mostly inaccessible to the international research community. Furthermore, the survey only includes 3D cadastre from a land use, land management and land registration point of view. Other cadastre, such as roads cadastre or historical buildings cadastre, are not included in the study.

The survey does not differentiate between publications in peer-reviewed journals, conference papers and other means of scientific publication, in, e.g., book chapters. The reason for this is twofold: First; publication of results in traditional peer-reviewed journals is not the most common way to publish results in the 3D cadastre research community, where other means of communicating results are, for example, (abstract- or fully peer-reviewed) conference papers and book chapters, such as in the proceedings of the aforementioned 3D cadastre conferences/workshops, resulting in a number of conference papers published in the conference proceedings. An example is the best practice 3D cadastre publication in 2018 [5], consisting of peer-reviewed chapters, and second; the literature survey by Paulsson and Paasch [4], of which the research presented here is a follow-up study, was not limited to peer-reviewed journal articles, but included other types of publications, such as conference papers.

Research topics in the legal category were examined in order to identify trends within those research issues. Although it would have been interesting and feasible to study trends also in the other categories, it did not fit into the scope of the paper.



During the survey of the most recent years' publications, we noticed the rather frequent existence of some topics in regard to classification of 3D cadastre research, such as standardization and 4D cadastre. We therefore extended our analysis to include these as an additional result of our investigation. They were found by searching for their presence in the publications titles and are therefore to be seen as indicators of emerging fields of 3D cadastral research. It was during the analysis noted that sub-topics, for example, standardization and visualization, could be identified by analyzing the titles, which are often more specific than the keywords. The survey has identified such sub-topics being subject for research in all four investigated categories.

We are of the opinion that the actual number of publications in each category is of less importance, since they only show the history of 3D cadastral research. It is rather the trends that are of interest, providing an insight in where research may be heading in the future and to act as input to discussions on possible gaps in research and possibilities to further research activities into areas not being in focus during the last decade.

Automated textual analysis methods, such as text mining through text categorization, to identify and organize, structure and categorize the context in 3D cadastre publications, have not been used in this study. The reason is that it was judged most methodically correct to use the same manual approach as in the Paulsson and Paasch study [4] to make them comparable.

We have identified two additional literature studies on 3D cadastre research, published in 2021 [10] and 2018 [11]—i.e., after the publication of the Paulsson and Paasch study. Their results are compared with the outcome of this study. The result of these studies is analyzed together with the results from this study. This study has focused on general trends regardless of geographical distribution of the 3D cadastre examples described in the literature. A geographical distribution of publications has already been provided in the one of the literature reviews mentioned above [10] and is therefore omitted from this study. A geographical oriented study on the distribution of the topics and sub-topics identified in this study may however be subject for future research, but does not fit into the scope of this paper.

Furthermore, text mining and other automated text analysis methods could be considered in future research. An automated comparison with similar research has not been made due to different approaches and terminology in the 3D cadastre domain. The main purpose of the study has therefore not been to make a comparison with other similar studies, except [4], but to show that other studies exist, although with different focus.

### 3. Studies in 3D Cadastre Research between 2000 and 2019

The Paulsson and Paasch survey [4] made a quantitative analysis studying 156 3D cadastre publications published between 2001 and 2011, dividing them into four classes: "Legal", "Technical", "Registration" and "Organizational". The study also analyzed whether a publication dealt with two or more subjects. The most dominant topic was registered as the major topic and the less dominant subject(s) were registered as secondary class(es). The study was limited to English language publications since non-English publications are mostly inaccessible to the international community. The study was a continuation of an initial case study by the same authors in 2011, analyzing the content of 3D cadastre publications [15].

Döner [10] presented a quantitative analysis of in total 434 publications from 2001 to 2019. The classification of subjects seems to be based on the Paulsson and Paasch classification, including the use of secondary subjects. The classification uses three classes: "Legal", "Institutional" and "Technical", instead of the four classes used in the Paulsson and Paasch survey.

Tekavec et al. [11] did not provide a quantitative analysis, but rather examples and discussions about data models, legal aspects and organizational aspects. They focused on studies between 2000 and 2017 and the challenges of introducing a 3D cadastre, as well as current topics and studies concerning 3D cadastre.

#### 4. Classification

Oosterom [16] mentions the identification of six key research challenges in the area of 3D cadastres: “(1) shared concepts and terminology (standardization), (2) full life cycle in 3D (not only the rights), (3) legal framework, (4) creation and submission of initial 3D spatial units, (5) 3D cadastral visualization, and (6) more formal semantics”.

Other examples of where classification of topics have been used are, e.g., the 3D Delft workshop 2001, where the sessions were divided into the categories technical, legal and organizational, and the 3D Delft workshop with a division of sessions into legal framework 3D cadastre, initial registration of 3D parcels, 3D data management and visualization, distribution and delivery of 3D parcels. Another categorization of 3D cadastre aspects [17] presents three categories of 3D cadastre, namely legal, technical and institutional. As in the previous Paulsson and Paasch survey [4], we have followed these classes, although we added a separate registration category. When it comes to registration, it may be argued that it is part of the legal framework since legal enforcement through registration needs a legal system as a basis, but also that it belongs to the technical framework since registration requires the use of data system, data storage, etc. Due to this ambiguity, we have found it relevant to assign it as a separate category.

The topics used for classification in this study are the same as used in the Paulsson and Paasch survey [4], which divided research on 3D cadastre into four main categories:

*Legal:* The legal category contains publications on topics such as real property rights, restrictions, responsibilities, real property, superficies solo cedit, security of tenure, legislation, subdivision, spatial planning, legal objects and the legal framework.

*Technical:* The technical category contains publications on topics such as database management, spatial data infrastructure, data models, GIS, visualization and geometrical representation, cadastral surveying, geometry, topology, exchange formats and the technical aspects of distribution and delivery.

*Registration:* The registration category contains publications on matters that concern the registration of 3D property in land administration systems, such as the content, storage, structure and maintenance of 3D property information. “Land administration system” refers to any system that stores 3D property information, such as land registers and purpose cadastres.

*Organizational:* The organizational category contains publications on institutional, management and capacity-building issues. Organization is primarily a question of efficiency and how to organize and manage 3D property. Examples of organizational issues include good governance, operational aspects and financial aspects.

Each publication has been classified according to its primary, i.e., dominant, theme, and, if existing, a secondary theme or themes being less dominant themes in the publication. Each of the 530 publications has been analyzed and assigned to one of four main thematic categories: “legal”, “technical”, “registration” and “organizational”.

#### 5. Legal Aspects of 3D Property

3D real property and associated RRRs are legal constructions. They can be recorded, registered in a 3D cadastral registration system and visualized in accordance with the existing level of technology available. 3D real property is a form of property, which legally can be considered as (part of) a physical object such as a building and rights attached to a land plot. The physical extensions (outside or internal walls, floors, etc.) often coincide with the legal boundaries, but the legislation in a country usually determines real property and what it is. The concept of real property is therefore more than a two-dimensional surface. It is ownership and other RRRs attached to a three-dimensional volume. Furthermore, different types of legislation other than land law may limit the content and physical extension of the rights connected to the property, such as planning legislation and environmental law.

Due to the variety of 3D property, it can be difficult to make comparisons. However, internationally, it is possible to find several different forms of 3D property rights [18]. The

independent 3D property refers to a volume of space that is subdivided and separated from the rest of the property, often being a larger unit, including several apartments or infrastructure objects. The condominium, or apartment, ownership is usually well defined. It often consists of three components, the ownership right to a part of a building, a share in the common property and membership in an owners' association. It is often used to subdivide a building into several separately owned apartment units. Two main types of condominiums can be identified, the condominium ownership (dualistic) model and the condominium user right (monistic) model [19]. The condominium ownership model means that the apartment is regarded as a real property unit and owned independently like a piece of land, and land and common parts of the building are jointly owned. The condominium user right model means that usually the building and the surrounding grounds are owned jointly by the condominium owners and the owner only has a share in the common property to which an exclusive right to use a certain condominium apartment in the building is connected.

To find a clear and unambiguous definition of 3D property is difficult and the types and definitions of it vary between countries and legal systems, as well as the terminology that is used to describe the 3D property [17]. To define the 3D property, one should examine the legislation of countries using 3D property legislation. Even though there does not seem to exist any internationally accepted definition of 3D property [18], it usually refers to real property that is legally delimited both horizontally and vertically [20].

## 6. Results

This study contains the results of a literature survey of 3D cadastre publications 2012–2020. The total number of publications during the nine analyzed years was 530, i.e., in a lower number of years, more than three times the number of publications from the 11 years of the previous study in by Paulsson and Paasch [4]. The results of the literature survey show the number of publications that belong to each category and the content of the legal category. This survey revealed, like in the Paulsson and Paasch survey [4], that the majority of publications could be assigned to more than one category. Often, two themes were addressed in the same text. This was dealt with by applying the same method as in the Paulsson and Paasch study by using primary and secondary themes for classification.

### 6.1. Distribution between Categories

As shown in Table 1, a total of 77 of the investigated 530 publications were assigned to the legal category, 254 to the technical category, 165 to the registration category and 25 to the organizational category. We also identified nine general publications, e.g., overviews, not possible to assign to a specific category. The least researched category was the organizational category, but with a comparatively low number belonging to the legal category as well. The technical category is by far the largest, with almost as many publications as the number of all the three other categories together. See Table 1.

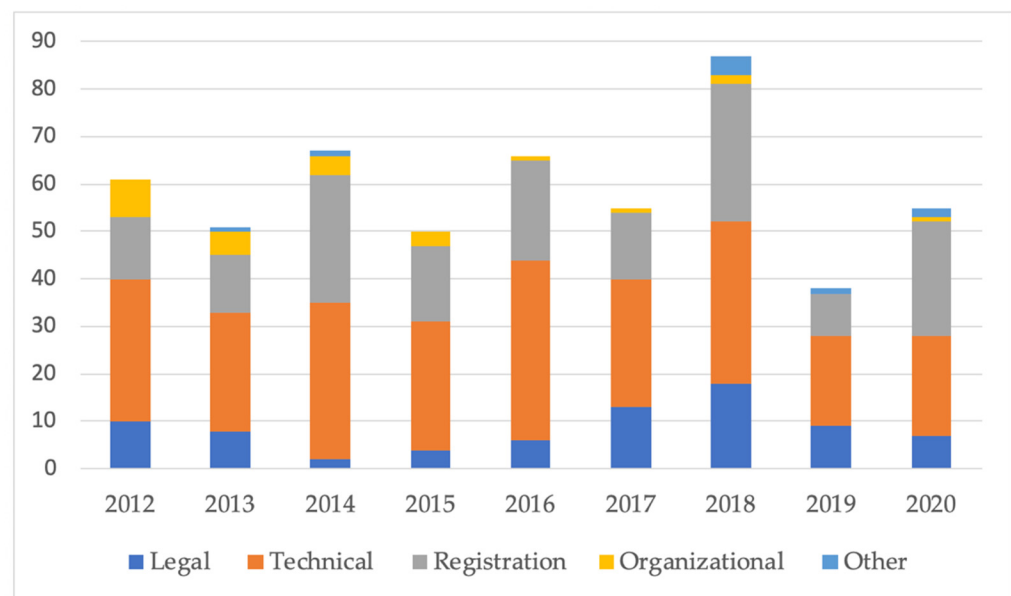
**Table 1.** Distribution of publications 2012–2020. () = secondary category.

Year	Legal		Technical		Registration		Organization		Other	Total Per Year	
2012	10	(7)	30	(9)	13	(22)	8	(2)	0	61	(40)
2013	8	(10)	25	(9)	12	(12)	5	(4)	1	51	(35)
2014	2	(6)	33	(17)	27	(6)	4	(3)	1	67	(32)
2015	4	(14)	27	(8)	16	(4)	3	(3)	0	50	(29)
2016	6	(13)	38	(12)	21	(7)	1	(5)	0	66	(37)
2017	13	(12)	27	(9)	14	(13)	1	(3)	0	55	(37)
2018	18	(13)	34	(17)	29	(27)	2	(7)	4	87	(63)
2019	9	(14)	19	(12)	9	(14)	0	(2)	1	38	(44)
2020	7	(15)	21	(11)	24	(11)	1	(3)	2	55	(35)
<b>Total</b>	<b>77</b>	<b>(16)</b>	<b>254</b>	<b>(104)</b>	<b>165</b>	<b>(116)</b>	<b>25</b>	<b>(32)</b>	<b>9</b>	<b>530</b>	<b>(352)</b>



The survey also revealed that most publications could be assigned to more than one category, e.g., technical as main category and registration as secondary category, or registration and organizational as secondary categories. The secondary subjects are marked with () in Table 1. The results show a more even distribution of categories, with 100 publications in the legal category, 104 in the technical category, 116 in the registration category and 32 in the organizational category, although the organizational category is also here by far the smallest one. See Table 1.

The number of contributions in the categories varies somewhat during the studied period, but with a fairly even distribution of around 60 publications per year. The year 2018 shows a peak of 87 publications, while in the year after, 2019, the survey only identified 38 publications. On average between these two years, there are again around 60 publications per year. This difference might be due to the 6th International Workshop on 3D Cadastre in Delft taking place in 2018 [9], to which many scholars prepared and presented their research, resulting in 57 publications, whereas there were only six conference related publications in 2019, and 10 in 2020. See Figure 4.



**Figure 4.** Distribution of publications in the main categories 2012–2020.

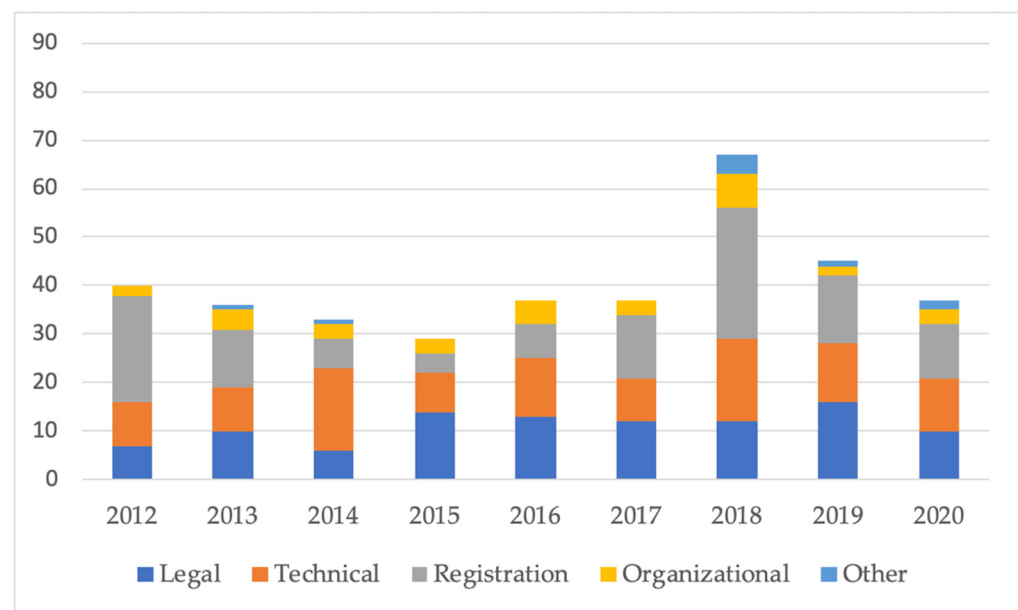
The majority of publications are conference papers, being 247 and counting for 47 percent of the total number of publications. In second place come peer-review journal publications with 216 publications, i.e., 40 percent. Then, there is a large gap down to book chapters, books and miscellaneous types, such as reports, counting 67 publications, i.e., 13 percent of the publications. The distribution between publication types is more or less the same throughout the investigated period, but with notable drops in conference papers in 2017 and 2019.

## 6.2. Distribution between Secondary Categories

It has not been possible to identify any correlation between a major category and the secondary categories. If, for example, the main topic is classified as technical, the secondary subjects can be, e.g., legal or registration, or legal and technical or any other combination of legal, technical, registration or organizational subjects. See Figure 5.

The Paulsson and Paasch study [4] focused on the legal perspective of 3D property. The legal theme is analyzed in regard to its legal context, e.g., the development of legislation and implementation. However, this study showed that a number of non-legal themes were the main subject of a number of publications. Therefore, this study, in addition to the legal

focus, also investigated the occurrence of sub-topics such as visualization, BIM (Building Information Modeling) and standardization.



**Figure 5.** Distribution of publications in the secondary categories 2012–2020.

Standardization has been subject for considerable research during the investigated period, especially ISO 19152, Land Administration Domain Model, LADM, which is an international standard for land administration published by ISO, the International Organization for Standardization [21]. The standard provides a terminology for land administration and makes it possible to produce a shared description of different formal or informal practices and procedures in various jurisdictions, including 3D real property and associated rights [22].

There are other standardization related topics published in 3D cadastral research, such as the INTERLIS [23], LandInfra [24] and CityGML [25] standards, but we have chosen to separate them due to the research interest for LADM, being a new standard published in the first year of the investigated time period. We have therefore classified the standardization related topics into an “LADM” group and a “Standardization issues not related to LADM” group.

Visualization of RRRs is the subject for 49 publications, i.e., nine percent of the investigated publications. The distribution does not show a yearly increase, but a random distribution ranging from two to eight publications per year, except 2018, peaking with 16 publications. The research has mainly been focusing on technical issues, being the subject of 32 of the 49 investigated publications. Legal and registration topics are dealt with in almost the same number of publications, seven and eight, respectively, but the organizational perspective has only been the subject for two publications. In five of the years, visualization only has publications in the technical category, which is the dominant category throughout the investigated period. See Table 2.

LADM is dealt with in 81 publications, which equals 15 percent of the publications in the study. It is possible to notice from the results that, in general, the number of LADM related publications increased during more recent years of the studied period, with the exception of 2019, which had a lower total number of publications. Additionally, here, the peak is in 2018 with 16 publications. The registration category is dominant, with almost half of the total number of LADM related publications focusing on such issues. See Table 2.

Standardization issues not related to LADM are dealt with in 20 of the publications, i.e., almost four percent of the publications. Here, also, an increase in the number of publications can be noticed during the second half of the period. Those publications mainly

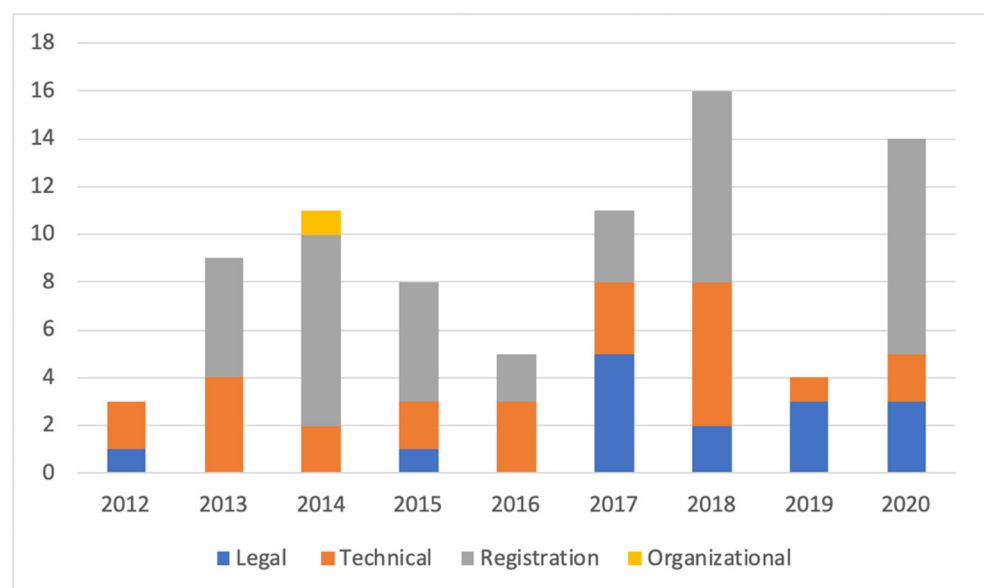
belong to the legislation category with 15 out of 20 publications, while the remaining five belong to the technical category. See Table 2 and Figures 6–8.

**Table 2.** Distribution of visualization, LADM and non-LADM related standardization sub-topics. L = Legal, T = Technical, R = Registration, O = Organizational.

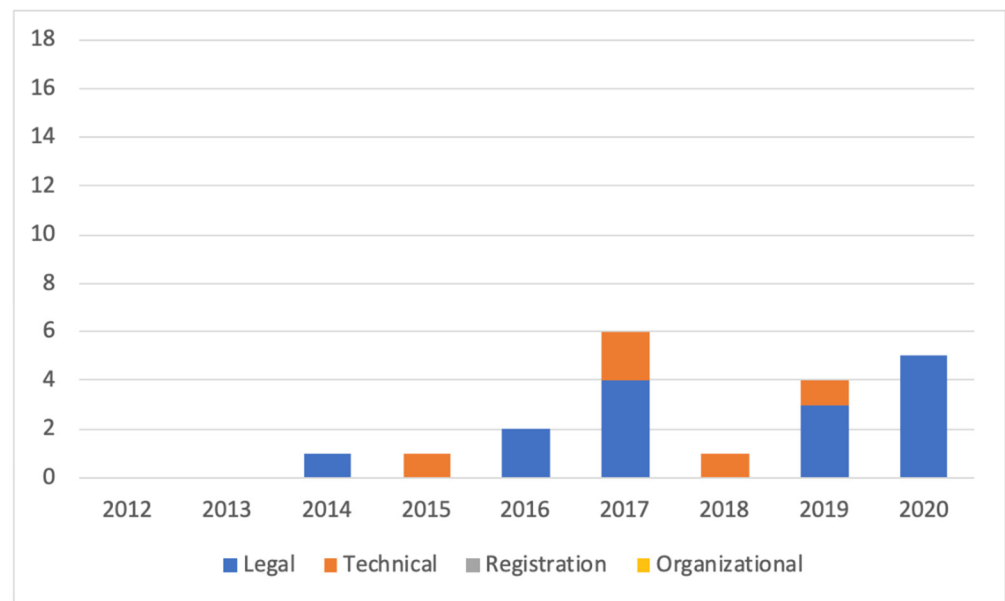
Year	L	T	R	O	Total	L	T	R	O	Total	L	T	R	O	Total
2012	0	2	1	1	4	1	2	0	0	3	0	0	0	0	0
2013	0	3	0	0	3	0	4	5	0	9	0	0	0	0	0
2014	0	6	2	0	8	0	2	8	1	11	1	0	0	0	1
2015	0	7	0	0	7	1	2	5	0	8	0	1	0	0	1
2016	0	2	0	0	2	0	3	2	0	5	2	0	0	0	2
2017	0	4	0	0	4	5	3	3	0	11	4	2	0	0	6
2018	0	4	0	0	4	2	6	8	0	16	0	1	0	0	1
2019	3	1	1	0	5	3	1	0	0	4	3	1	0	0	4
2020	2	4	6	0	12	3	2	9	0	14	5	0	0	0	5
<b>Total</b>	<b>5</b>	<b>33</b>	<b>10</b>	<b>1</b>	<b>49</b>	<b>15</b>	<b>25</b>	<b>40</b>	<b>1</b>	<b>81</b>	<b>15</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>20</b>



**Figure 6.** Distribution of visualization sub-topics.



**Figure 7.** Distribution of LADM related standardization topics.



**Figure 8.** Distribution of non-LADM related standardization topics.

## 7. Analysis

The results from the literature survey are analyzed below in relation to the research areas, with focus on the legal category. In addition to that, identified trends in 3D legal research during the studied period are examined. Since the topic of the paper is legal research, the analysis focuses on legal issues and trends and identified topics within that specific area.

### 7.1. Research Areas

It can be noticed that the number of publications in recent years have increased substantially, with more than three times the amount but in less years. The number of publications belonging to the legal category has decreased in relation to the other categories, also as a secondary theme, which might be explained by the fact that in many countries, the legal system has developed in recent years and now already is in place. Registration and implementation are now more in focus, as the next steps of the introduction of 3D property. The increase in the technical category might be explained by the current focus on standardization, which requires a discussion about the technical aspects of this. The number of organizational publications has increased in relation to the others since the previous study, which could be explained by an ongoing transition from the stage of establishment of the 3D property system to the management stage. On the other hand, as a secondary theme, organizational aspects have decreased. Previously, organization was primarily mentioned as a side aspect in connection to other issues, but now when implementation is more in focus, it has become a more important theme than before.

Any communication process would be of no or only limited value if there was no agreed method of communication, e.g., by having an established theme specific vocabulary. The role of terminology can, in our opinion, not be overestimated in communication and information interchange. Without any agreement, it is not possible to achieve any effective communication or comparison. Therefore, any comparison needs a common terminological framework as a basis for the classification to be made. This challenge was also mentioned by Paulsson and Paasch in the first 3D literature survey [4] discussing that “3D cadastre” is a term with many meanings. It is sometimes used as a general term for three-dimensional property, but sometimes only used to describe the actual cadastre, or real property registration system. Apartment ownership is also a form of 3D property and a number of different terms can be used for this form, such as “condominium” or “property strata”. The quantifiable numbers, such as the number of authors and

countries, analyzed in a publication can be counted and quantified in a literature study, but a classification based on non-standardized terms will be influenced by the views of those making the classification based on how the different terms and content of the publication are interpreted, based on the judgements and expertise of the classifiers.

Analyzing the contents of the legal category, it can be noticed that the information that is registered, visualized and standardized is based on legislation. Even though there are several country descriptions that also include legal issues, they are often presented merely as an introduction to the main subject and therefore counted as a secondary issue or perhaps not even that. Advanced technical solutions are presented, but it is sometimes not clear whether they will be possible to implement and compatible with existing legislation. It might be the case that the authors assume or know that the legal foundation is already in place, or they simply do not reflect on this. Still, as in the previous study, the legal issues are to a large extent related to national issues, although some comparative studies between a number of countries have been made.

Going through the publications in the legal category, some main topics can be noticed, occurring to a larger or smaller extent. One of these topics is standardization/LADM, which we have also identified as a theme in the classification presented above. LADM related research has become more common as a topic in recent years, introduced as a new standard, as mentioned above. Sub-terrain related issues, such as underground cadastre, layer approach and solutions for providing rights for the subway or parking facilities, are also dealt with in the publications. Visualization has also been mentioned, and is mainly dealt with in publications belonging to the technical category, but legal issues are also mentioned in relation to this, such as presenting legal boundaries in 3D.

Further topics are types of rights, RRRs and the introduction of such rights. Often this is dealt with related to the legislation in one country. In general, it is still possible, as in the Paulsson and Paasch survey, to notice that a number of the publications are case studies describing national systems, although there are some comparative studies between countries, or comparing a national system with more general types of rights. Some of these comparative studies include just a few countries, while others are more general studies incorporating several countries with different legal families and systems. More general issues related to legal systems can also be identified as a topic, such as legal framework, integration of legal aspects, legal foundations, developing legislation, 3D cadastral systems, legal aspects of creating a 3D cadastre, purpose of 3D property and analysis of laws. Several of these deals specifically with public law and public law restrictions and implementation, as well as E-government. Terminology issues are also included here, although not that frequently.

Research on digitalization has increased in recent years and is the topic of several of the more technically oriented publications, although it is also a topic of legal studies, including BIM, cadastral data models and digital information, as such. Spatial relations is a topic connected to this, presenting spatial objects, correlation between legal and physical property, legal boundaries and cadastral boundaries.

Finally, we have identified a legal topic group on ownership relations discussing management, common property and co-ownership. More land administration-oriented topics are also brought up, such as land administration and management, expropriation and studies on how to deal with informal situations.

## 7.2. Trends in 3D Property Legal Research 2011–2020

The Paulsson and Paasch study [4] published in 2013 presented some areas where the authors proposed that further research should be carried out within the legal field. These were comparative studies on the use of 3D property concepts, an international perspective on publications, 3D property terminology, delimitation and definition of 3D property, and cooperation between 3D property unit owners. Related to the international perspective on publications, it was discussed that research on national systems should be written from an international perspective and be (re)published in English.



The survey presented in this paper shows that the suggested topics have not been in focus in 3D cadastral legal research, analyzing the publications in the legal main category or subcategory. The analysis was conducted by searching for keywords such as “comparative”, “terminology”, “cooperation” and synonyms thereof in the title. When in doubt, the publication was subject to further investigation.

We have identified an increase in the number of legal publications from 28 publications to 77 publications and in organizational publications from 6 publications to 25 publications from 2001–2011 to 2012–2020. Even if there is an increase in actual numbers, there has actually been a decrease in both topics from 17% to 15% and from 3% to 2%, respectively. Furthermore, this survey only identified five publications on analyzing comparative studies on the use of 3D property concepts; five publications analyzed 3D property terminology, delimitation and definition of 3D property; cooperation between 3D property unit owners were analyzed in 3 publications. This indicates that the recommended increase in legal and organizational topics as described in the Paulsson and Paasch study only to a limited degree has been acknowledged by the scientific community. Examples from the surveyed publications are Grassi [26] (comparative studies on the use of 3D property concepts), Sürmeneli et al. [27] (3D property terminology, Delimitation and definition of 3D property) and Grigoryan and Paulsson [28] (cooperation between 3D property unit owners). A survey on 3D cadastre in 2018 showed that all participating countries were operating a digital cadastre and aiming to improve, e.g., storage and visualization capabilities, and that some countries are in the process of modernization of their legal system to allow registration of 3D units RRRs [29]. This increased focus on national 3D legal issues has however not been identified in legal research, where technical and registration issues still are the dominant areas of research, even if there is an increase in research in specific sub topics; visualization of legal issues since 2019, legal issues on LADM since 2017 and non-LADM standardization in the last part of the investigated period, as seen in Figures 6–8.

It has been difficult to estimate if an increased national publication has been made to a greater extent, since it has not been possible to find and categorize publications written in all other languages than English, but we can see that there seem to be an increased number of countries adding research to the 3D property research field. Whether this is related to more national studies being published internationally is difficult to estimate, but a reason is probably that 3D cadastre issues are brought up in more countries, when investigating or implementing such systems nationally.

It seems like 3D property terminology has not been discussed to a great extent, but has increased in relation to standardization, and also in connection to LADM as a new subject in 3D cadastre development and research, being published after the Paulsson and Paasch survey [4]. National definitions are important and sometimes described in connection with country descriptions, but there has also been a more general terminology discussion where ‘3D cadastre’ has been replaced with ‘3D land administration’ [30]. When it comes to delimitation and definition of 3D property, this has partly been achieved with the research on LADM in connection with 3D property. Cooperation between 3D property unit owners has been paid less attention, with only few publications, mainly related to management issues, in particular related to condominiums. The distribution of the visualization, LADM and other standardization topics during the investigated period is shown in Table 2 in Section 6.2.

We also identified publications describing 4D cadastre, 3D property valuation, BIM (as mentioned earlier) and marine related topics such as governance of 3D LADM compliant marine cadastres [31]. They are, however, few in number and therefore not analyzed in detail in this study, but subject for future research, as they may be indicative of new emerging research areas in 3D cadastral research.

## 8. Discussion

Despite the recommendations from the previous Paulsson and Paasch study [4], no increase in legal or organizational topics could be noticed from the survey. We have

not investigated the reasons for this, but some possible explanations could be provided. Themes and sessions at conferences, workshops and Special Issues in journals are to a large extent still focused on technical and registration issues. Many researchers in the field of 3D cadastre have a more technical background and could not easily provide research on more legal issues, and for researchers with a legal background, the area may seem too technically oriented. As mentioned, it may be perceived that the legal system and regulations are already in place and that there is no need to investigate such issues further. Legal research may also be presented in national languages and have thus been omitted from this survey. More recent comparative studies on development of terminology (see, e.g., [3,29,32]) may however lead to an increased awareness on the value of legal publications, e.g., comparative studies, when there has been sufficient time to carry out the research.

Publications from additional countries have emerged or increased during the studied period, although the researchers contributing to the 3D cadastre research are to a large extent the same as before. However, new countries bring with them new issues to discuss, such as water rights and informal rights. Perhaps, more nationally specific studies are being made, but presented only in national languages and thus not included in this study. The distribution of publications by the country of authors has not been subject for this study, since it is covered in one of the other literature studies [10].

From the study, it has been possible to discern some research areas, where some are rather new and some of them have increased in volume since previously. Although new topics of legal research have emerged, they do not correspond to a large extent with the topics proposed for future research in the previous study by Paulsson and Paasch [4]. Among the new identified sub-topics can be mentioned visualization, standardization, LADM, 4D cadastre, BIM, valuation and water related 3D cadastre topics.

Visualization, LADM and non-LADM related standardization are topics that have been subject for research, but other sub-topics such as 4D cadastre, BIM, valuation and water related 3D cadastre research are less frequent than other topics. They are, however, part of the continuous development of three-dimensional real property concepts and it is, in our view, likely that they will be encountered in future research publications.

The results presented in this study can only partly be analyzed in relation to the Tekavec et al. [11] and Döner [10] studies. The reason is that they are not conducted in the same way and did not use the same methodology. The study by Tekavec et al. presented a study on two periods, 2000–2010 and 2011–2017. The first period focused on internationally recognized studies, discussions and publications, 3D cadastre and data models, and legal and organizational aspects of 3D cadastre. The last period analyzed studies concerned with 3D cadastre after 2010, including challenges related to 3D cadastre from a legal perspective, introducing a 3D cadastre and examples of current topics and studies. It is an interesting study providing examples and discussions, but it did not produce any quantitative data.

The study by Döner [10] is a quantitative study covering 2001–2019. It uses three classes for classification: legal, institutional and technical, making a comparison of the investigated years in this study, 2012–2019, and the Paulsson and Paasch [4] study difficult. Furthermore, Döner limited the research to publications published on the FIG Working Group on 3D Cadastres web page, whereas this study has used a broader approach, thus identifying 475 publications during the same period 2012–2019, instead of 283 publications in the Döner study. Despite the difference in number of publications, it is still possible to see common trends in both surveys. This study has identified more publications each year, which can be related to our wider data collection method, not using the FIG website as our only source. It is notable that both studies have identified a drop in publications 2019. Furthermore, both studies have identified conference papers as the most common way to publish 3D cadastral research, followed by journal articles, even if there are fewer articles in relation to conference papers in the Döner survey. The presence of legal publications is higher in Döner, identifying 34 % of the publications as legal, whereas this study identifies 15% of the publications in the same period as legal.

This inconsistency between the studies is, in our opinion, based on the different methods of data collection and the lack of common definitions and terminology when attributing a publication to a specific class. It is, however, notable that both studies have identified non-legal publications collectively as the major topics in both surveys.

This research indicates that strictly quantitative literature surveys in 3D cadastral research are of limited value unless there is a standardized method for selecting the publications subject for investigation and commonly accepted definitions to be used as basis for classification. 3D cadastral research statistics should therefore be interpreted as trends in the directions that 3D cadastral research is heading and not as statistically validated quantitative data.

## 9. Conclusions

The research on 3D cadastre publications presented covering 2012–2020 used the same classification of topics as a previous study that analyzed the years 2001–2011, dividing 3D cadastre publications into four major categories/topics: legal, technical, registration and organizational. This study showed that the recommendations in the earlier study concerning increased future focus on legal and organizational topics has been met numerically by the scientific community, due to the extended amount of publications, but in relation to the other classes the number still remains rather low. There are, however, still only few publications on, e.g., terminology and cooperation, as recommended in the previous study. Taking into account that the investigated period produced more than three times as many publications as the previous, the relation between the 3D cadastral research classes has remained more or less the same. Technical and registration topics are still in majority, whereas legal and organizational topics are less researched. Many non-legal publications would have benefitted from having a somewhat wider focus that includes legal and/or organizational aspects within the more technically and registration-oriented topics. It is not a goal in itself to produce as many legal oriented publications as possible, but we think that the 3D cadastre research community would benefit from the inclusion of some legal perspective in publications on technical, registration and organizational topics, since the 3D cadastre is based on legislation that will have to be considered in one way or the other.

Since 3D property and cadastre is now being introduced in more countries, that type of research would facilitate the introduction, by providing a framework in a legal and institutional sense. However, it might be a challenge to make researchers understand this benefit and include also such issues, even when technical or registration solutions are developed. Technical solutions may be more general and internationally adoptable, while the legal and organizational issues to some extent have to be investigated in a more national context, which might make it less interesting to the researchers and calling for an increased number of researchers to be involved, also those not that familiar to 3D cadastre issues.

Within more legal oriented research, we think that it still could be useful to address the research topics mentioned in the previous study, such as terminology, cooperation, delimitation and definition of 3D property, comparative studies of 3D property concepts and international comparative studies. National case studies are of value for the research community, but an increased focus on international comparative studies would also be beneficial and put the national systems into an international context. For a broader picture of where research in the field of 3D cadastre is heading, a similar study of trends within the technical and registration categories would also be of interest, which could thus be a topic for future studies.

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