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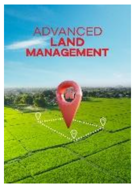

Three-dimensional cadastre-from two-dimensional plan to three-dimensional digital model

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Abstract

The three-dimensional (3D) cadastre first came to the agenda in 2001 with a workshop organized by the International Federation of Surveyors (FIG). In the past two decades, many scientific meetings, academic studies and pilot projects have been carried out on 3D cadastre. At the same time, there have been significant developments in 3D data collection techniques, data modelling, 3D visualization, policy and institutional structures. In this study, the effects of these developments on cadastre are evaluated. In addition to the literature review, to make a comparison and evaluation, the questionnaire results conducted by the FIG 3D Cadastres Working Group in 2010, 2014 and 2018 were examined. As a result of the examination, it is seen that the demand for 3D cadastre data has increased with the need for planning and sustainable management of cities. This increasing demand has expanded the use of digital 3D models to represent cadastral data. Legal and organisational structure of Turkey is advantageous for 3D cadastre. Data modelling and pilot projects for 3D cadastral were carried out in Turkey in recent years. Although technological advances offer significant opportunities, the applicability and sustainability of 3D cadastre projects requires the creation of a workflow that supports the use of international standards and digital models beyond pilot projects.

1. Introduction

The significant increase in the world population in the last two centuries has led to intensification of land use, especially in urban areas. This increasing trend in population has changed the relationship between land and people over time, increasing the importance of land ownership [1]. Accordingly, a system to clearly and unambiguously record ownership of land was required. Although various names (land registration, land recording, land administration, etc.) are used to describe this system, today this system is generally called cadastre [2-4]. Cadastre forms the basis of land management by recording the geometric (boundaries) and legal (rights, restrictions and responsibilities) information of real estates. Until today, a standard cadastre has not been developed due to differences in legal structure, technical and economic opportunities [5]. Various classifications and definitions have been made for cadastre, taking into account criteria such as priority purposes, types of recorded rights, techniques used in data collection [6].

Although the right of property is applied to a space from legal point of view, the boundaries of the right of property are traditionally represented on cadastral maps by using two-dimensional (2D) parcels. However, as a result of the increasing use of the vertical dimension of the land in especially cities, since the beginning of the 2000s, due to the increasing population, the need for the cadastre to refer to a space instead of a plane when representing the property boundaries has come to the fore, and the concept of three-dimensional (3D) cadastre has emerged [7-9]. Difficulties in registration and representation of different types of land uses (limited real rights such as right of superficies, right of easement) and 3D objects (such as individual units and utilities) affecting below and above the land surface have further increased the interest in 3D cadastre [10]. The first examination of 3D cadastre within the scope of a postgraduate study was with the doctoral thesis completed in Delft Technical University in 2004 [11]. However, the issue of 3D cadastre was addressed at the international level for the first time in a workshop organized by the International Federation of Surveyors (FIG) in Delft, Netherlands in 2001. After this workshop, it was decided to establish a working group called 3D Cadastres in partnership with the third (Spatial Information Management) and the seventh (Cadastre and Land Management) commissions of FIG. However, until 2010 the 3D Cadastres group had no activity other than special sessions held at the annual FIG working week meetings. At the 24th FIG congress held in Sydney in 2010, it was decided to reconstitute the 3D Cadastres working group and a website [12] was created to include studies and developments in this field [13]. The organized and planned activities of the 3D Cadastres working group since 2010 are shown in Table 1.

Table 1. Organized and planned activities of the FIG 3D Cadastres working group

Year	Activity Explanation
2010	Creation of the FIG 3D Cadastres website. Sending the first 3D Cadastres questionnaire to the participants.
2011	Second 3D Cadastres Workshop (16-18 November, Delft, Netherlands).
2011- 2013	Organizing 3D Cadastres sessions at FIG Working Weeks. Marrakech, Morocco, 18-22 May 2011, Rome, Italy, 6-10 May 2012, Abuja, Nigeria, 6 - 10 May 2013.
2012	Third 3D Cadastres Workshop (October 25-26, Shenzhen, China).
2013	Publication of the 3D Cadastres special issue of Computers, Environment and Urban Systems.
2014	Presentation of four-year results and 3D Cadastres session at the 25th FIG Congress (June 16-21, Kuala Lumpur, Malaysia).
2014	Sending the second 3D Cadastres questionnaire to the participants. Fourth 3D Cadastres Workshop (9-11 November, Dubai, United Arab Emirates).
2015- 2017	Organizing 3D Cadastres sessions at FIG Working Weeks. Sofia, Bulgaria, 17-21 May 2015, Christchurch, New Zealand, 2-6 May 2016, Helsinki, Finland, 29 May - 2 June 2017.
2016	Fifth 3D Cadastres Workshop (18-20 October 2016, Athens, Greece).
2018	Publishing the book named Best Practices 3D Cadastres by FIG.
2018	Sixth 3D Cadastres Workshop (2-4 October 2018, Delft, Netherlands).
2018	Publication of the 3D Cadastres special issue of the ISPRS International Journal of Geo-Information.
2018	Sending the third 3D Cadastres questionnaire to the participants.
2020	Publication of the 3D Cadastres special issue of Land Use Policy journal.
2021	Seventh Workshop on 3D Cadastres (October 12-14, 2021, New York, USA).
2021	Eighth 3D Cadastres Workshop (24 June 2021, Amsterdam, Netherlands).
2023	Ninth 3D Cadastres Workshop (11-13 October 2023, Gavle, Sweden).

According to Table 1, 3 questionnaires have been carried out in 2010, 2014 and 2018 with the participation of country representatives, 8 workshops have been organized, 1 book and 3 special issues in 3 international journals has been published, apart from the special sessions held at the FIG congresses and annual meetings on 3D cadastre research. The 2010 questionnaire of the FIG 3D Cadastres working group was evaluated in [14], the 2014 questionnaire was evaluated in [15], and the 2018 questionnaire was evaluated in [16] separately. However, there is a need for studies in which all questionnaires are handled together in order to evaluate the development of 3D cadastre in a more reliable way. In this study, in order to evaluate the development of 3D cadastre and make a comparison, besides the literature review, the results of the questionnaires conducted by the FIG 3D Cadastres Working Group in 2010, 2014 and 2018 are examined. As a result of this examination, the main trends and development areas for 3D cadastre were determined and the studies of different countries in these areas were compared. The material and method used in the study are introduced in the second section. The findings based on the 3D Cadastres working group questionnaires and literature reviews are presented in the third section. Finally, the study ends with the conclusion section.

2. Method

In this study, the method of examining the questionnaires prepared by the FIG 3D Cadastres working group and answered by the researchers of the participating countries was adopted to determine the development in the field of 3D cadastre. The basic trends and development areas for 3D cadastre were determined by examining the questionnaires of the years 2010, 2014 and 2018, which were used as materials. Then, the studies of different countries in these determined areas were compared.

The main purpose of the questionnaires, which have been carried out every four years since 2010, is to reveal the current status of the work in the field of 3D cadastre around the world, the plans for the next four years and the progress made compared to the previous four years. In this way, it is aimed to increase cooperation by sharing the knowledge and experience of different countries. The basic structure of all three questionnaires is almost the same. Chapter titles and question numbers in chapters have been retained to facilitate comparison. However, in the questionnaires prepared for 2014 and 2018, some questions were simplified and made more understandable and new questions were added at the end of the relevant section. In Table 2, the main sections of the 2018 questionnaire of the FIG 3D Cadastres working group and the contents of these sections are given.

In the FIG 3D Cadastres working group, which has participants from 42 countries in total, the 2010 questionnaire was answered by the participants of 36 countries, the 2014 questionnaire was answered by the participants of 33 countries, and the 2018 questionnaire was answered by the participants of 29 countries. The number of countries responding to all three questionnaires is 23. The names of these countries alphabetically are Argentina, Australia (Queensland and Victoria States), Canada (Quebec Province), China, Croatia, Finland, Germany, Greece, Hungary, India, Israel, Kenya, Malaysia, Netherlands, Nigeria, Poland, South Korea, Southern Cyprus, Spain, Sweden, Switzerland, Trinidan and Tobago, Turkey.

Table 2. FIG 3D cadastres working group 2018 questionnaire chapter and its contents [17-18]

Number	Title	# of question	Content
1	3D Parcels	23	Legal base, 3D Geometric Structures, ISO 19152:2012 (LADM) Compliance
2	Utilities	9	Independent Registration, Rights Used, Intersecting Parcels
3	3D Representation of Individual Units	14	Building and Individual Unit Registration, Definition of Boundaries, Common Use Areas, Land Share
4	3D Coordinate	8	Absolute and Relative Heights, Representation in Database
5	Representation of the Third Dimension	8	Using Elevation Model, Storing Elevation Model in Database
6	4th Dimension (Time)	10	Time-Changing Boundaries, Timeshare
7	3D Right, Restriction, Responsibility	14	Land Registration System, Integration of 2D and 3D Registration
8	Database	15	LADM Schema, 3D Geometric Structures, Validity
9	3D Survey Plans	26	3D Representation, Content of Survey Plans, Regulations, 3D Survey Methods
10	Web Based 3D Representation	9	3D Data Formats, Cartographic Rules
11	Statistics	11	Smallest/Biggest Parcel Sizes, Permissible Limits
12	Progresses	7	Goals in Previous questionnaires, Progress, Challenges

3. Results

This section first presents the findings from a review of the FIG 3D Cadastres working group questionnaires. Then, under the subtitles determined by this review, the findings of the development in the 3D cadastre studies are discussed. At the end of each subtitle, the situation in Turkey is also evaluated to provide an opportunity for comparison.

3.1. 3D Cadastre Questionnaires

The evolution of the FIG 3D Cadastre questionnaire design is illustrated in Figure 1. The first 3D cadastral questionnaire designed and sent to country representatives in 2010 consists of 9 sections. The second 3D cadastral questionnaire of 2014 was updated by adding 3 new sections. These sections are respectively web-based 3D representation, statistics and developments. Another change in the 2014 questionnaire was the first use of the term Land Administration Domain Model (LADM) in some of the questions in sections 1 and 8. With this approach, it is aimed to adopt the terminology offered by LADM, which was accepted as an ISO standard in 2012, in questionnaires and to facilitate comparisons between questionnaires. The third 3D cadastral questionnaire design change in 2018 consisted of 24 new questions added to the questionnaire. The final questionnaire was prepared by adding new questions to sections 1 (6 questions), 4 (2 questions), 5 (2 questions), 6 (4 questions), 7 (1 question), 9 (7 questions) and 12 (2 questions). New questions added are about registration of 3D usage rights at sea, monitoring temporal changes, institutions responsible for registration and mapping, use and recording of height information, legal resources in 3D representation, accuracy, pilot studies and legal barriers to a fully 3D cadastre. Since the new sections added to the 2014 questionnaire and the new questions added to the 2018 questionnaire were determined as a result of the answers given to the previous questionnaires and workshops on different dates, they are important in terms of showing the development and trends in the 3D cadastre research.

It is observed that there has been a decrease in the number of countries answering the questionnaires over time. The number of countries responding to the 2010, 2014 and 2018 questionnaires was 36, 33 and 29, respectively. While the studies in the field of 3D cadastre increases, the decrease in the number of countries participating in the questionnaire can be interpreted as no progress or change in the new questionnaire period for the countries that responded to the previous questionnaire. Austria, Bahrain, United Kingdom, France, Indonesia, Italy, Kazakhstan, Nepal and Russia, which participated in the 2010 questionnaire, did not participate in the next two questionnaires. Brazil, Denmark, Macedonia and Norway, which participated in both the 2010 and 2014 questionnaires, did not respond to the 2018 questionnaire. The number of countries that answered all three questionnaires is 23.

The main difficulty in making an evaluation by comparing the three questionnaires conducted in 2010, 2014 and 2018 with each other is that the number of sections and questions of the questionnaires is not the same, as explained in this section. In addition, when the answers given by the countries to the questionnaires are examined, it is seen that short answers (such as yes, no, none) were given to many questions, and many fields were left blank. Especially in the first 3D cadastral questionnaire in 2010, there was no integrity in the answers given to the questionnaire questions due to the inability to create a common terminology and the differences between countries in the use of terms such as cadastre, land administration, registration and recording. However, the 8th section, which is common to all three questionnaires, and the 12th section added to the questionnaires since 2014 (12.4: the three most important obstacles for 3D cadastre and 12.5: pilot studies) are suitable for comparison in terms of containing more detailed explanations. The main findings that can be reached from the responses of the countries for the 2010 questionnaire are that there are studies on 3D digital database design in Sweden and Italy, and that volumetric parcels can be created and registered in Australia and Canada. In addition, it is stated that case studies have been carried out for 3D registration of utilities and complex buildings in the Netherlands, Sweden and Norway.

The first finding of the 2014 3D cadastral questionnaire is that in the answers given to the questions in the third part of the questionnaire, case studies were conducted for the 3D registration of individual units in Australia and China. It has been tried to examine whether LADM, which was accepted as an ISO standard in 2012, has an effect on the 3D cadastre, with the answers given to the 8th section of the 2014 questionnaire. Accordingly, only 5 of the 29 participants who answered the relevant question stated that there are partial studies on LADM in their countries (Australia, Czech Republic, China, Croatia and Greece). When the answers given to the questions of the 10th section, which is one of the new sections of the 2014 questionnaire, are examined, it is seen that digital data models such as CityGML (City Geography Markup Language), KML (Keyhole Markup Language), PDF (Portable Document Format), LandXML (Land eXtensible Markup Language) and 3D data sharing studies are mentioned in Germany, Brazil, China, Croatia, Spain, Sweden, Switzerland and Canada. In the 12th section of the 2014 questionnaire, the participants are asked questions about the progress in the past four years, expectations for the next four years, and what are the three most important obstacles to the development of 3D cadastre. Responding to these questions, the participants stated that their main expectation is the creation of a digital database. The obstacles stated for the development of 3D cadastre vary. The most common ones are lack of legal regulation, lack of digital data, lack of institutional policy, lack of academic studies, lack of economic resources and the need for experienced personnel.

When the answers given by the countries to the 2018 3D Cadastre questionnaires are evaluated, it is seen that Germany, Czech Republic, Finland, Croatia, Netherlands, Malaysia, Portugal and Singapore reported modelling studies compatible with LADM, unlike the 2014 questionnaire. In addition, it was stated that pilot projects are planned or ongoing in the Netherlands, Israel, Switzerland, Sweden, Hungary, Malaysia, Singapore, Slovenia and Turkey. However, details on these pilot projects were not given. It is stated that the main obstacles to the development of 3D cadastre are mainly legal and institutional issues (10 of 19 participants).

As a result, when the development in the FIG 3D Cadastre questionnaire design and the responses of the participating countries to the questionnaires are evaluated together, it is seen that the most active field of activity in the development of 3D cadastre is the use of data models in the cadastre. In addition, it is noteworthy that pilot studies were expressed in the 2018 questionnaire. The resolution of legal and institutional issues is gaining weight as the main challenge for real 3D cadastre development. These topics, obtained from the examination of the questionnaires, need to be examined in more detail to reveal their effects on 3D cadastre research. These topics are covered in the following subtitles of this section.

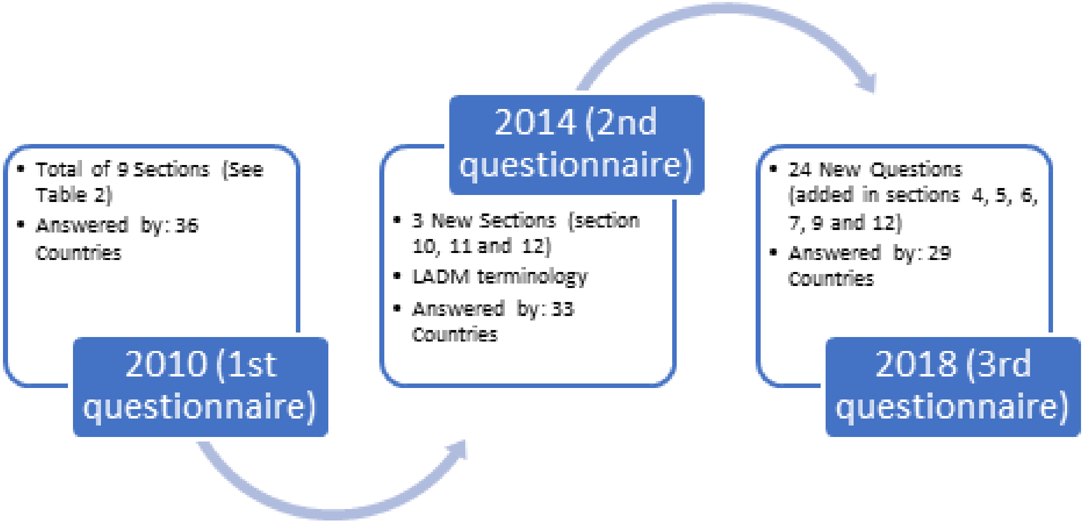

Figure 1. Development of 3D cadastre questionnaire

3.2. Use of Data Models in Cadastre

According to the questionnaire studies examined, one of the most important developments in the field of 3D cadastre is the widespread use of data models for 3D modelling of cadastral data. In particular, LADM, which was accepted as an ISO standard in 2012, has been shown as the main reference in the development of the country's 3D cadastral data model by the participants of some countries responding to the questionnaire. Some of the countries where these studies that base on LADM have been published are Australia [19], Czech Republic [20], Israel [21], Korea [22], Malaysia [23], Poland [24], Serbia [25] and Greece [26]. The evolution of LADM, a conceptual model aimed at standardizing data in the field of land administration, is given in Figure 2. LADM was first announced as the 'Cadastral Domain Model' after the 22nd FIG congress held in the United States of America in 2002 [27]. With this name, the work continued until 2008. In 2008, the first step towards becoming an ISO standard was taken with FIG's application to ISO under the name of 'Land Administration Domain Model' (NWIP-New Work Item Proposal). LADM was adopted as the draft standard (CD-Committee Draft) in 2009. The current version (v1) of LADM was adopted in 2012 and received the standard number (ISO 19152: 2012). FIG's application for revision of LADM was accepted by ISO TC (Technical Committee) 211 in May 2018. The revision process, which will take four years, is planned to result in the adoption of the new version (v2) of LADM in 2022. Besides FIG, revision of LADM is also supported by international organizations and institutions such as World Bank, Open Geospatial Consortium (OGC), United Nations Global Geospatial Information Management (UN-GGIM) and Global Land Tool Network (GLTN). The second version of LADM is aimed to include new modules (Information Models) for real estate valuation, spatial planning, indoor representation and modelling of sea boundaries. While the current version of LADM supports 3D cadastre, the new version is planned to include detailed 3D spatial profiles (predefined data structures) for different spatial data types. In addition to third dimension, geometry, topology and time profiles will be included in the new version of LADM to model the fourth (time) dimension [28].

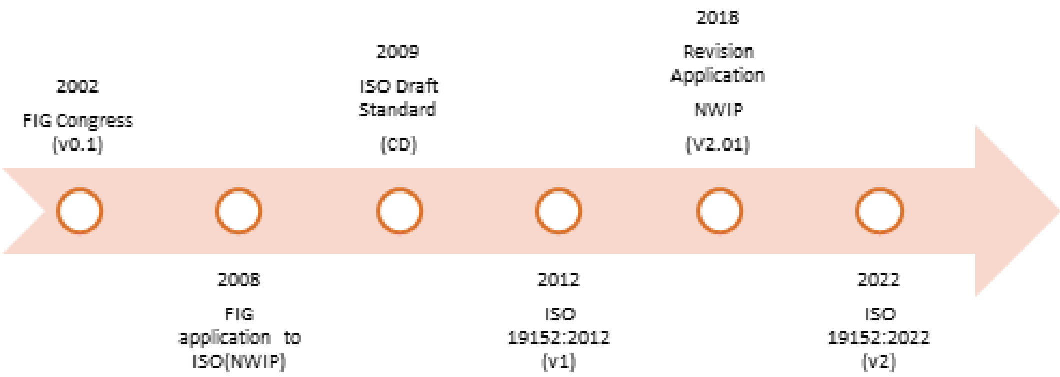

Figure 2. Development of ISO LADM 19152

In addition to LADM, which is a conceptual model, spatial data models are also preferred for the 3D digital representation of cadastral data. The most common of these digital models are BIM (Building Information Modelling) and CityGML models. These models are particularly advantageous for the 3D representation of individual units in buildings and associated rights. Studies were carried out for the 3D representation of individual units in the cadastre using BIM or GML (Geography Markup Language) based data models in Australia [29-30], China [31], India [32], the Netherlands [33], Sweden [34] and Greece [35]. Especially BIM models has been widely used in the 3D design, modelling, construction and renovation processes of buildings in the fields of architecture, engineering and construction by replacing traditional CAD (Computer Aided Design) models in recent years [36]. Similarly, CityGML, which is a common information model for the representation of 3D city objects, defines classes and relations of objects, taking into account their geometric, topological and semantic properties, unlike other vector data structures. CityGML is implemented with the GML application scheme published by OGC and ISO TC 211 (International Organization for Standardization- Technical Committee- Geographic information/ Geomatics). 3D models produced with CityGML find a wide range of application area from urban planning to disaster management, from cadastre to tourism [37]. In addition, IndoorGML, which is an OGC standard and developed for network analysis in indoor spaces, offers opportunities to model indoor spaces and their boundaries in 3D cadastre, thanks to the topological and semantic structure and relations it contains. There are studies in which IndoorGML is used alone or in combination with LADM [38-40]. Besides, LandInfra, as a new OGC standard implemented with GML (InfraGML), has a potential for 3D cadastre. LandInfra has been developed to cover objects both above and below the land surface and can represent administrative boundaries, parcels, easements and individual units [41].

Studies on modelling cadastral data in Turkey according to international standards were first initiated in 2006 with the Turkish National Geographic Information Systems (TUCBS in Turkish) project. Within the scope of this project, 10 geographical data themes, including Land Registry-Cadastre and Building data themes, were developed by the Ministry of Environment, Urbanization and Climate Change (MoEUCG) General Directorate of Geographical Information Systems (GDGIS) in 2012. Land Registry-Cadastre [42] and Building [43] data themes were developed based on ISO 19152 LADM and INSPIRE (Infrastructure for Spatial Information in the European Community) Cadastral Parcel data theme [44]. GDGIS updated 12 of the total 32 national geographic data themes (coordinate reference systems, administrative units, geographical place names, cadastre, building, address, elevation, orthoimage, transportation networks, hydrography, geology, land cover) in 2018. The remaining 20 geographic data themes are planned to be updated within a schedule [45].

3.3. Pilot Projects

In the questionnaires examined, the participants of 9 countries stated that there are pilot projects completed or ongoing in their countries for 3D cadastre. Three of these countries are Australia, the Netherlands and Sweden. The common feature in the pilot projects of these countries is that the aim of the project was determined as a 3D digital representation of the individual units in the buildings. The survey plans of the selected buildings in the pilot study area in Queensland, Australia, and the drawings of the individual units in these buildings were digitized and digital 3D models were produced in the KML format compatible with the LADM conceptual scheme. These 3D models are then presented on the web with 2D cadastral parcels. A test study was also carried out to determine how useful and understandable the produced models and web-based presentation are for users and citizens from different disciplines [46]. In the last 3D cadastre project carried out in the Netherlands, it is aimed to determine whether BIM models can be used in the legal process of creating individual units. In order to produce the 3D models, the 2D boundaries of the buildings shown on the cadastral maps and the drawings of the individual units attached to the notary deeds were taken as reference. The produced models were visualized in 3D in GIS and web environment together with 2D cadastral parcels [33]. In the pilot project in Sweden, 3D digital models based on IFC (Industry Foundation Classes) produced with reference to the legal documents (property formation dossiers) and maps (cadastral index map) used for the establishment of property rights in the individual units were used to represent the legal and physical space of the individual units in the buildings [47]. In addition to these three current pilot projects included in the questionnaire in 2018, 3D representation of independent sections in China [48], production of 3D cadastral parcels in Poland [49] and web-based display and querying of 3D cadastral objects in Russia [50] were aimed. In addition to pilot projects related for directly 3D cadastre, some other 3D cadastre studies encountered in the literature review are supported under project titles such as Smart Cities and Digital Twins. In these studies, it is aimed to create an infrastructure for sustainable city design, management and planning by integrating digital 3D property information with data such as noise, energy, air pollution, mobility and temperature [52-55]. This situation can be considered as an indication that the demand for 3D cadastral data has increased so much that it cannot be limited to legal purposes only. From this point of view, it is seen that there is a need to consider future 3D cadastral researches and projects from a broader perspective.

A project called 3D City Models and Cadastre was announced by the General Directorate of Land Registry and Cadastre (GDLRC) in February 2018 in Turkey. In the announcement, it is stated that the pilot studies of the project, which started in Ankara, are planned to last for four years. The main purpose of the project is to create 3D models of the individual units and to associate these models with the title information of the individual units. While the project was continuing, it was stated in the announcement made by GDLRC that floor models were started to be created within the scope of the project and the integration studies of the produced models with the Land Registry and Cadastre Information System (LRCIS) continued [56]. The stages of the GDLRC 3D Cadastre project are given in Table 3 [57]. In 2019, GDLRC shared a test demonstration showing how the individual units and related information will be presented with the project. In Figure 3, a screenshot taken from this demonstration of the project in the testing phase is given. When Figure 3 is examined, it is seen that the 3D building model, the floor plans of the individual units in the building and the legal information of the selected individual units can be presented together.

Table 3. Stages of GDLRC 3D cadastre project

Stages	Activity
Geodetic Studies	Establishment, marking and measurement of ground control points
Photogrammetric Studies	Aerial image acquisition with digital aerial cameras
Data Processing/Generation	Processing of GPS/GNSS-IMU (Inertial Measurement Unit) data, digital surface/terrain model generation, point cloud and orthophoto generation
3D Modeling	Generating 3D floor and building models
Data Control and Improvement	Verifying and optimizing the position and geometry of 3D models
Model texture	Overlaying 3D building models using oblique and vertical aerial images
Individual Units Modeling	3D modeling of individual units from architectural projects
Data attribution	Associating the produced 3D models with GDLRC legal data

HGM-Atlas and HGM-Sphere applications, which were opened for use by the General Directorate of Maps (GDM, HGM in Turkish) on January 24, 2019, are important in terms of creating an infrastructure for the presentation of models produced for 3D cadastre. GDM has developed these applications in order to meet the map needs of citizens and public institutions on the internet with national means, to eliminate foreign dependency and to provide a basis for digital transformation. Şirin [57] showed that 3D models with different data structures developed for cadastre can be presented with HGM-Atlas and HGM-Sphere applications. In this way, it will be possible to prevent the payment of fees paid to applications abroad in the presentation of cadastral data to users and the collection of personal data through foreign applications.

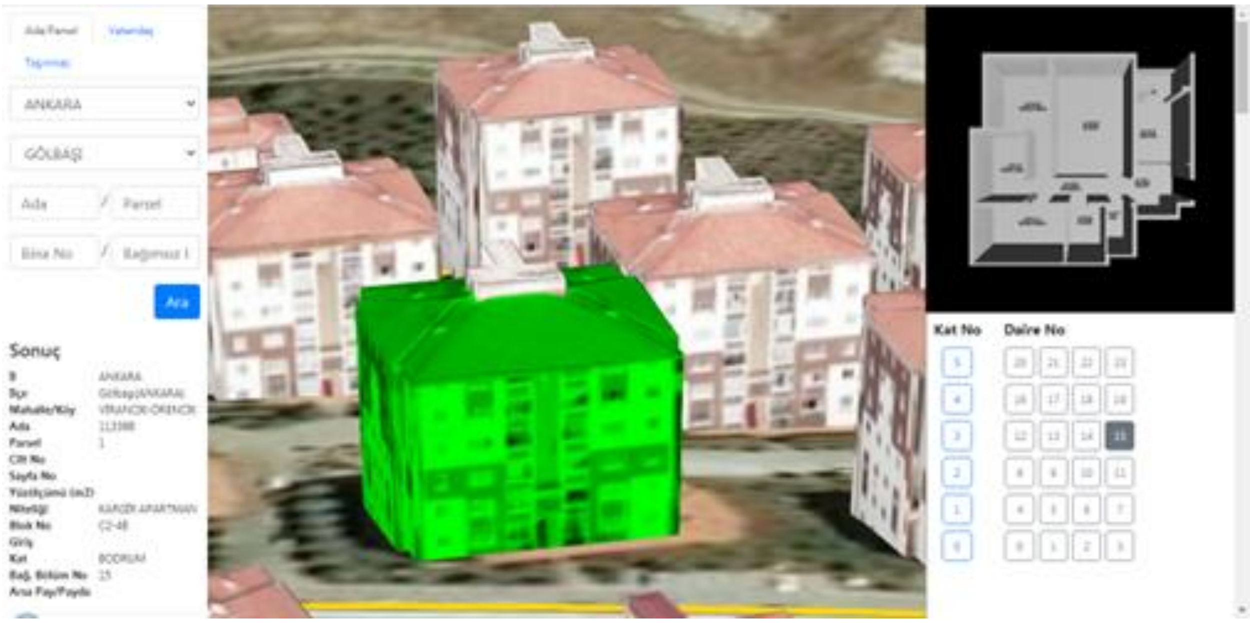

Figure 3. TKGM 3D cadastre project test data [58]

3.4. Legal and Institutional Issues

Considering the examined 3D cadastre questionnaires and related literature, it is seen that the least discussed topics in 3D cadastre projects and research are legal and institutional issues [59]. As a result, both pilot projects and academic studies are mainly focused on solving technical problems. Legal bases form the basis of the cadastre. If legal definitions of 3D real estate objects do not exist, measuring and registering them will be meaningless. When the questionnaires are evaluated, it is seen that some countries have made legal arrangements or the legal infrastructures of the countries allow the creation of 3D real estate units. For example, in Scandinavian countries such as Sweden [60] and Norway [16], legal arrangements have been made to improve the process of registering individual units. In the Netherlands, there have been regulations for adding 3D digital data belonging to utilities and buildings with complex use cases to notary deeds [51]. In addition, in some states of Australia [61] and Canada [62], it is legally possible to create volume-constrained property units. These property units are called volumetric parcels in Australia and air-space parcels in Canada. Although there are laws regulating the use of the vertical dimension of the land in each country, a generally accepted 3D property definition does not seem possible since the legal and institutional structures of the countries are unique to them. The inability to develop a common terminology in legal matters is another challenge. Even researchers from the same country can use different words to express the same concepts. This makes it difficult to compare legal studies.

Cadastre systems only make sense if they exist within an institutional structure. For this reason, the institutional dimension of the 3D cadastre includes the duties and responsibilities of the public registration and mapping institutions. In addition, the success and sustainability of the developed projects requires the creation of a workflow between the stakeholders who produce and use 3D digital data. It is to ensure that the authorities, responsibilities and standards are determined and implemented as a state policy in the production, updating and sharing of data that will provide this workflow. As in the legal structure, there is no partnership in the institutional structures of the countries when it comes to cadastre. In some countries, such as Austria and Romania, registration and cadastral mapping are the responsibility of different institutions. In some countries, cadastre may be carried out under the responsibility of local governments (such as Sweden and Norway), while in others (such as Turkey and the Czech Republic) it is the responsibility of the central government. While the cadastral institutions of some countries are only responsible for mapping property boundaries, in others it is the duty of these institutions to produce value maps (such as Germany) and produce country maps (such as the Netherlands) [63-64]. This situation causes the meaning of the word cadastre to differ from country to country. In the e-mail sent by the FIG 3D Cadastres working group management to the researchers of the participating countries in June 2020, it was requested to evaluate the use of the expression 3D Land Administration instead of 3D Cadastres and their opinions on this subject were requested. As the reason for the name change, it was stated that the land administration should be better known by different countries and that the compliance with ISO 19152 LADM, which is based on the activities of the working group, is ensured. A decision on the name change is planned before the adoption of the planned LADM update in 2022.

When the legal and institutional structure in Turkey is evaluated, it can be said that there is an advantageous structure for the development of 3D cadastre. The boundaries of the property right on the land, which are guaranteed by the Constitution, are defined in the Civil Code and the land and individual units are registered in accordance with the relevant laws. The same institution (GDLRC) is responsible for the registration process and the production of cadastral maps. Both GDLRC and GDGIS, which is responsible for updating geographic data themes, operate under the same ministry (MoEUCG). In addition, there have been recent developments in which strategies have been adopted as state policy in determining the cadastral data content according to international standards and sharing them for different purposes of use. On November 7, 2019, a Presidential Decree was published in order to establish the target and strategy for the national spatial data infrastructure, to ensure inter-institutional coordination, and to update the geographic data themes to be prepared in accordance with national or international standards. A total of 32 geographic data themes are listed in the decree, and there are also cadastre and building data themes [65]. Shortly after the publication of the presidential decree, the National Smart Cities Strategy and Action Plan, covering the period between 2020 and 2023, was published in the Official Gazette and entered into force on 24.12.2019. Among the activities in the action plan are the reference architecture model to be developed and the integration with the national spatial data infrastructure [66]. These developments show that cadastral data will be integrated with other data and will be used more frequently for sustainable urban management and planning in the future.

4. Conclusion

The inadequacy of existing cadastral systems in registering and representing some situations that arise in the modern world, with the effect of developing technology, has led to the 3D cadastre research being on the agenda for the last two decades. In this study, the effects of developments in 3D cadastre research and projects on cadastre were evaluated. In order to make a comparison and evaluation, besides the literature review, the results of the questionnaires conducted by the FIG 3D Cadastres Working Group in 2010, 2014 and 2018 were examined. The reasons such as the fact that the number of sections and questions of the questionnaires belonging to different years are not the same, that the questionnaire participants generally give short answers to the questions and questions that are left blank make it difficult to compare the questionnaires. However, with the new sections and questions added to the questionnaires since 2014, the participants are asked to explain the pilot projects in their countries and the obstacles for the 3D cadastre. When these new sections and the questions that are common and frequently answered in all three questionnaires are examined, it is seen that the most significant effect of the progress on the cadastre is the use of ISO 19152 LADM in the 3D modelling and representation of the cadastral data. In the 2014 questionnaire, only 5 of the respondents stated that their country's cadastral data models are partially compatible with ISO 19152 LADM, while in the 2018 questionnaire, 12 participant countries stated that their cadastral data models are compatible with ISO 19152 LADM. Updates of data models produced in Turkey based on ISO 19152 LADM are carried out under the responsibility of GDGIS. In addition, the adoption of digital transformation as a state policy with the Presidential Decree on Geographic Information Systems and the National Smart Cities Strategy and Action Plan published in the Official Gazette in the last months of 2019 supports the use of digital models in the cadastre. In addition to ISO 19152 LADM, although various studies on the use of IFC and GML-based data models for 3D cadastre are found in the literature, it is seen that this situation is not reflected in the questionnaires. It is necessary to address this issue in the next questionnaire period, and to determine the place of common standards and data models in 3D cadastre applications by developing new questions or improving existing questions. As a result of the examination of the questionnaires, it has been determined that pilot projects for 3D cadastre have been carried out or are ongoing in countries including Turkey (Netherlands, Israel, Switzerland, Sweden, Hungary, Malaysia, Singapore, Slovenia and Turkey). Within the scope of these projects, 3D data collection, modelling and display studies were carried out. Legal and institutional issues emerge as the least discussed issues in 3D cadastre research. In the 2018 questionnaire, respondents are asked about the three most important obstacles to 3D cadastre development in their country. Of the 19 respondents who answered this question, 10 stated legal and institutional issues among these barriers. The legal and institutional structure in Turkey is advantageous for 3D cadastre. Although technological advances offer important opportunities, the viability and sustainability of 3D cadastre projects requires the creation of a workflow that supports the use of international standards and digital models beyond pilot projects.

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Author contributions

Fatih Döner: Conceptualization, Methodology, Data curation, Writing-Original draft preparation, Validation. **Cemal Bıyık:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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