Analysing 3D Land Administration developments and plans from 2010 to 2026

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Key words: LADM, ISO19152, Questionnaire, Land Administration, 3D Cadastre trends, assessment rubric

SUMMARY

This paper is the follow-up of 4 earlier analysis papers on the 3D Cadastres / Land Administration questionnaires. The last FIG questionnaire 2022-2026 was just analysed and the FIG working week 2023 (Kalogianni et al. 2023, and in that paper the creation or update, organization and initial analysis of the results from the 4th FIG 3D Land Administration Questionnaire, as an activity of the FIG Working Group 3D Land Administration 2022-2026 was presented. By sharing this information among the countries/ jurisdictions, a comprehensive inventory will be created. It is expected that cooperation will improve, by learning from the different countries and jurisdictions, to support future developments in the field of 3D land administration. It is noted that, as LADM is finding increasing recognition (Kalogianni et al., 2021), it has been further incorporated into the various sections of the questionnaire.

The completed questionnaires, per country are fully available via the participants' page of the 3D Land Administration Working Group website. The responses have been analyzed and reported in various publications (van Oosterom et al. 2011, van Oosterom et al. 2014 and Shnaidman et al., 2019), while the initial analysis of the 4th Questionnaire has been recently presented by Kalogianni et al. (2023).

This paper aims to provide an overview of the developments and plans from the initial questionnaire in 2010, till the future plans for 2026, based on the analyses that have been previously carried out (van Oosterom et al. 2011, van Oosterom et al. 2014 and Shnaidman et al., 2019) and highlighting the results of the analysis from the latest questionnaire. The initial results from the latest questionnaire have been presented by Kalogianni et al. (2023), providing the main outcome from the current status (December 2022), while highlighting the priority axes till 2026 related to the developments of 3D LAS.

What is more, an assessment rubric is developed by the team that prepares and analyses the questionnaires, that is actually a scoring of the responses in the various sections of the four (4) questionnaires This assessment process is the first time that is being carried out and it is executed for eight (8) countries and presented in this paper.

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1. INTRODUCTION

An efficient and reliable land administration system is the foundation for a strong economy of a country and sustainable development. Since cadastre is perceived as the core of any land administration system, linking the three essential components therefrom: people-to-land relationships through Rights/Restrictions/Responsibilities (RRRs), it is expected to provide a complete and up-to-date information regarding parcels boundaries and the associated relations (Kitsakis et al., 2018).

The majority of currently operational land administration systems around the world are 2D-based, while there are various countries/ jurisdictions that have developed operational components of 3D LAS and in parallel, the topic has been the subject of much research and debate (Lemmen et al., 2003; van Oosterom, 2013; van Oosterom, 2018, van Oosterom, 2022). Part of this activity was coordinated and supported by the international community of surveyors, namely the International Federation of Surveyors (FIG) Joint Commission 3 and 7 Working Group on "3D Cadastres". It is noted that at the FIG Working Week 2023 in Florida, the new name of the FIG Working Group was decided to change in order to include LADM (ISO 19152, the Land Administration Domain Model) and has been formed as "Land Administration Domain Model/ 3D Land Administration"; in short, "LADM/ 3D LA".

The Questionnaires on 3D Cadastres have been conducted three times by the Working Group, in 2010, 2014 and 2018, while the 4th Questionnaire on 3D Land Administration is conducted as a successor of the previous three questionnaires and presents the status of December 2022. The original structure and numbering of the questions as introduced at the first edition of the questionnaire (2010), have been carefully maintained, while specific questions were altered over time, where needed from 2010 to 2022, to provide a better understanding of the questions to the responders. By sharing this information among the countries/ jurisdictions, a comprehensive inventory will be created. It is expected that cooperation will improve, by learning from the different countries and jurisdictions, to support future developments in the field of 3D land administration. It is noted that, as LADM is finding increasing recognition (Kalogianni et al., 2021), it has been further incorporated into the various sections of the questionnaire.

This paper aims to provide an overview of the developments and plans from the initial questionnaire in 2010, till the future plans for 2026, based on the analyses that have been previously carried out (van Oosterom et al. 2011, van Oosterom et al. 2014 and Shnaidman et al., 2019) and highlighting the results of the analysis from the latest questionnaire. The initial results from the latest questionnaire have been presented by Kalogianni et al. (2023),

providing the main outcome from the current status (December 2022), while highlighting the priority axes till 2026 related to the developments of 3D LAS. What is more, an assessment rubric is developed by the team that prepares and analyses the questionnaires, that is actually a scoring of the responses in the various sections of the four (4) questionnaires This assessment process is the first time that is being carried out and it is executed for eight (8) countries and presented in this paper.

The rest of the paper is structured as follows: Section 2 reflects on the structure and context of the four questionnaires and their evolution from 2010 till today, while providing more insights on the results of the last edition of the questionnaire. Moreover, Section 3 provides a rubric to assess the countries/ jurisdictions based on their answers at the various questions of the questionnaire and provides the initial results for seven countries aiming to initiate the discussion in this field. Finally, the last Section is devoted to discussion and next steps of this research.

2. STRUCTURE AND ORGANISATION OF THE FIG 3D LAND ADMINISTRATION QUESTIONNAIRES FROM 2010 TO 2022

A brief reflection on the structure and organization of the four questionnaires that have been developed till today is presented in Sub-section 2.1, providing the basis for constructive conclusions in Section 3. Furthermore, the main conclusions drawn from the last questionnaire regarding the status of 3D LAS at the end of 2022 related to LADM and the plans and priorities of the countries for the coming four (4) years are presented in Sub-section 2.2.

2.1 FIG 3D Land Administration Questionnaires from 2010 to 2022

The questionnaire, from its first edition, aims to address the most important aspects related to 3D LAS and it occurs every four (4) years, so that important technological developments and advances in the legal aspects can be reported per country. As already mentioned, the structure and numbering of the questions as introduced at the first edition of the questionnaire (2010), have been carefully maintained, while specific questions were altered over time and also added. Specifically, the first edition of the questionnaire comprised ten (10) sections, while the other three sections comprised thirteen (13) sections.

In all editions, the first nine (9) sections and the last one (Other Issues – referring to the contact details of the responders) remain the same, with differences in the number of questions. The first nine sections are:

- Section 1. - General/ applicable 3D real-world situations
- Section 2. - Infrastructure/ Utility Networks
- Section 3. - Construction/ Building Units
- Section 4. – X/ Y Coordinates
- Section 5. - Representation of 3rd dimension: height (or depth)
- Section 6. - Temporal issues (4th dimension)

- Section 7. - Rights, Restrictions and Responsibilities (RRRs)
- Section 8. - The Cadastral Database (Digital Cadastral Database - DCDB)
- Section 9. - Plans of survey (including field sketches)

What is more, some questions are reshaped or, where necessary additional information is provided, to stipulate a better understanding to the responders. This was the case especially, at the second edition of the questionnaire, where it has been noticed that some questions in the first questionnaire were ambiguous to the responders, as most of the countries could provide the same answer. This is caused by the fact that terms may have slightly different meaning in different countries around the world, which is especially true for more abstract concepts such as 3D Cadastre and 3D parcel, while the level of expertise of the responders influence the responses. Therefore, one of the biggest changes in the second edition of the questionnaire was that the LADM was explicitly referred as basis for the used terminology, while a few notes (including an informal and a formal definition of a 3D parcel) were added. Moreover, some example answers and completed questionnaires (for Queensland and The Netherlands) were provided, without trying to be leading.

From the Sections' perspective, the topics of dissemination of 3D LA-related information (Section 10.) and the provision of statistical information (Section 11.) from the countries have been added in 2014 and are maintained till the last edition of the questionnaire, while the section of the reflection (Section 12.), introduced in the second edition of the questionnaire with five (5) questions, has been enriched after the third edition. As a result of the rapid development of the 3D LA advances worldwide, the aspects introduced in this section refer to pilots' execution in the field of 3D LA, as well as the advances in the legislative framework. It is worth noting that due to new developments and context, significant modifications within the questionnaires' context are found in Section 1, Section 3, Section 7 and 9, mostly lying on the inclusion of new questions that arise from the top trends on the 3D LA domain, as well as the wider scope of the LADM Edition II. Finally, there are nineteen (19) countries/ jurisdictions that have participated in all four (4) questionnaires till now.

2.2 Status of 3D LAS around the world in 2022 related to LADM and key challenges for the coming four years

All members/ countries of the FIG 3D LA & LADM WG have been requested to provide information both regarding the current situation at the end of 2022 and the expectations/ plans for 2026. This current questionnaire is backwards compatible with the previous three, while some questions have been refined for clarification and several new questions have been added at the end of the sections, introducing the topics of BIM in land administration, 3D land administration applications and implementation of the LADM.

The new questions introduced in this questionnaire aim to provide more insight about the following aspects:

- developments related to ISO19152 LADM, specifically related to country profiles;
- BIM-based sources used for 3D LAS registration and relevant specifications that may apply to the country;
- operational solutions related to previous question;

- developments related to national 3D City Models and
- other types of objects that require both real-world time and database time to be registered at the LAS.

In total, thirty-seven (37) countries responded to the Questionnaire in 2022, from which four (4) are new participants (did not participated before). In terms of consistency, there are also four (4) countries that have participated in the previous three (3) questionnaires, but not at the current one.

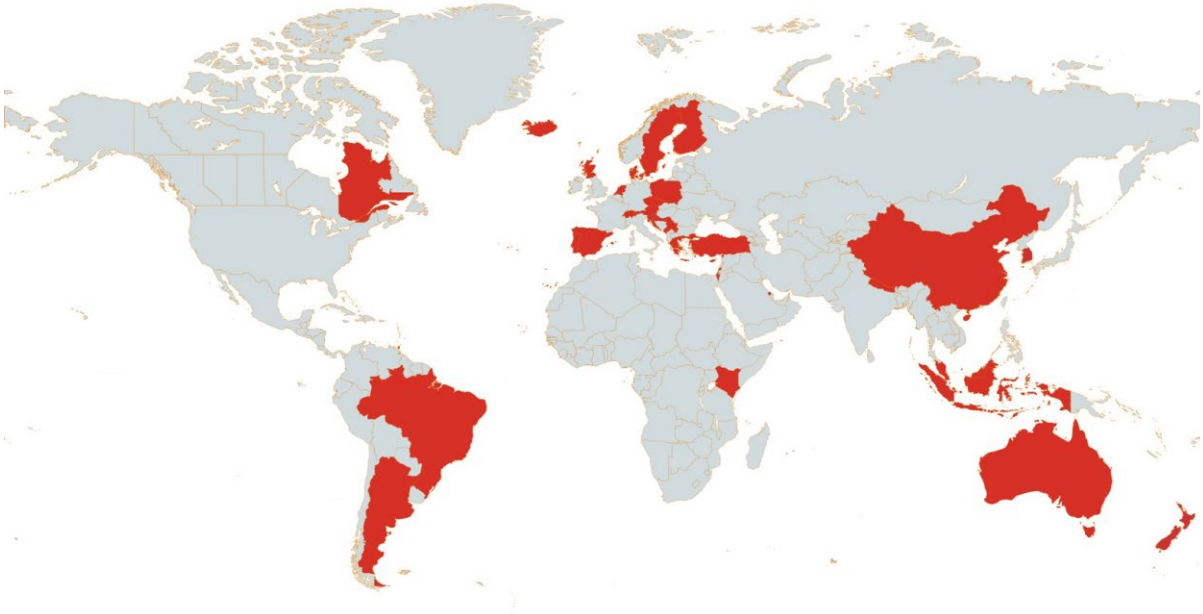

Figure 1. Spatial distribution per continent of the countries that have participated in the 4th Questionnaire of 3D Land Administration (current status of 2022 and expectations for 2026) (Kalogianni et al., 2023).

Regarding the use of ISO19152:2012 LADM as a formal model for the 3D parcels currently (end of 2022), four (4) countries answered positively (Shenzhen in China, Finland, Malaysia and Scotland), while Singapore mentioned that this is under investigation and Sweden that LADM is being used conceptually. It is worth noting, that 35% of the responders declared that their cadastral database is based on LADM. This answer has many aspects, to be further analysed, as there were answers that declared that the database is partly or fully compliant with LADM, or not explicitly mapped with LADM concepts, or that this is achieved using particular software tools, so the level of compliance relies on those (i.e. Trinidad and Tobago uses Trimble Landfolio). In this light, there are ten (10) countries that responded positively in the question of considering adopting LADM till 2026.

Almost half of the countries (49%) that have participated in the questionnaire have not currently developed a country profile based on LADM. From those that have developed, a 41% declares that the country profile has either been developed at a preliminary stage (i.e. mapping between LADM classes and the respective LAS concepts), or it has been developed by academia and can be accessed through relevant publications. Twenty-four (24) countries provided data about the future plans for 2026, and their priorities can be organized in three categories as follows:

- **Legal aspects:** provision of legislation that can support 3D in land administration; raise awareness on the legal community (lawyers, notaries, etc.) about the advantages of 3D LA; convince government that 3D is needed and shall invest on it.
- **Organisational aspects:** capacity building on the personnel and support for reform (including training) to be able to handle 3D LAS; engagement of private sector and stakeholders and their involvement in the development of clear guidelines; cultural shift towards 3D LA from government, organisations and professionals.
- **Technical aspects:** software development in line with the latest 3D developments; usage of the latest technologies; interoperability between data and systems; support/ guidelines for 3D capture, management and dissemination of the surveying-related information; digital submission of (surveying) information.

3. INITIAL ASSESSMENT RUBRIC FOR THE EVALUATION OF THE RESPONDERS

An assessment rubric for the FIG Questionnaire on 3D Land Administration is presented in Sub-section 3.1, providing scoring for the responses in the various sections of the questionnaire. Furthermore, this is used to provide the scoring, using the average Manhattan Distance computed, for 6 countries for their responses at the four questionnaires from 2010 till 2022 (Sub-section 3.2).

3.1 Assessment rubric for the FIG Questionnaire on 3D Land Administration

Based on the analysis of the results of the responses from the 4th FIG Questionnaire on *3D Land Administration*, an initial attempt to create an assessment rubric to evaluate the countries is developed and presented in this section. As presented in the following table, for nine (9) sections of the questionnaire a scoring method is developed. For Section 4 related to the (X, Y) coordinates the respective scoring method was developed, but following the overall assessment it appears to be less useful and hence it is not included in the overall evaluation, while the last two sections concerning country's overall reflection and the contact details of the responder are excluded, as they do not provide information that can be assessed.

Table 1. Rubric assessment for the FIG Questionnaire on 3D Land Administration

Scoring	Description
SECTION 1 - GENERAL/ APPLICABLE 3D REAL-WORLD SITUATIONS	
0	3D spatial units are not recognised
2	3D spatial units recognised, but not as part of Cadastre/ LAS (with different legal system from 2D)
4	Legislation existing for 3D spatial units
6	Strata units and common property are recognised
8	Fully general 3D volumes are treated as first-class cadastral objects
10	Full LADM based support of 3D volumes.
SECTION 2 - INFRASTRUCTURE/ UTILITY NETWORKS	

0	Utility networks not recognised
2	Networks recognised but not as part of Cadastre/ LAS
4	Jurisdiction has privately owned/leased, etc. networks within Cadastre/ LAS
5	Networks recorded (within Cadastre/ LAS) in 2D
6	Networks are fully defined in 3D
8	Network sections are first-class cadastral objects
10	Full LADM based support of network objects
SECTION 3. - CONSTRUCTION/ BUILDING UNITS (including spatial extents of units defined in 3D by physical walls/objects)	
0	Units/apartments/construction units are not recognised
2	Units/apartments/construction units are recognised but not as parts of Cadastre/ LAS
4	Special legislation for 3D units, etc. exists
5	Meaning of boundaries is defined (middle of wall, etc.)
6	Full definition of buildings including common property
7[1]	Tenure is fully defined on units (protection against sale of 2D parcel)
8	Units are a first-class cadastral object
9[2]	BIM is mandated for registration of units in certain classes of buildings
10	BIM is mandated for registration of all units
SECTION 5. - REPRESENTATION OF 3rd DIMENSION: HEIGHT (OR DEPTH)	
0	No ground surface model or definition of 2D parcel elevations exists
2	2D parcels are defined in relation to local ground level, but not quantified
4	Jurisdictional height datum exists and is referenced
6	Ground surface elevation model exists but not is referenced by DCDB
7	Z-values are assigned on cadastral corners
8	Ground surface elevation model is carried within the DCDB (or is strongly connected)
10	Digital twin of the jurisdiction exists, including ground surface elevations
SECTION 6. - TEMPORAL ISSUES	
6a	**Real-world history**
4	Time-limited spatial units are defined, but actual limits are not being recorded within Cadastre/LAS
6	Time-limited spatial units exist and temporal limits are defined within Cadastre/LAS
8	Moving boundaries are defined in X/Y/Z/time
10	Full digital history of boundary changes is supported (including subdivisions)
6b	**Legality of title**
0	A full historic search of titles is needed going back to the big bang!
5	A limited historic search of dealings shall be carried out
10	The registry of titles is current, and the single current title is definitive
6c	**History of database**

[1] Note that the respective question was not included in the first edition of the Questionnaire - 2010
[2] Note that the respective question was included first time in the 4th edition of the Questionnaire - 2022

0	The database(s) are point of time only (as up-to-date as possible)
2	Snapshots are taken at regular intervals
6	1D time – keeping reverse or forward deltas to track database changes
7	Some spatial units have 2 dimensions of time
8	Keeping a history of the database representation (The Versioned Object paradigm in LADM)[3]
10	Keeping real-world history as well as database representation history (The 2D time paradigm in LADM) [4]
SECTION 7. - RIGHTS, RESTRICTIONS AND RESPONSIBILITIES (RRRs)	
0	RRR information not available to Land Administration jurisdiction
4	Some distinctions in 3D RRRs compared to 2D
6	Same definition of 2D and 3D RRRs (and temporal if permitted) exist
10	RRRs are defined in form equivalent to LADM (or STDM)
SECTION 8. THE CADASTRAL DATABASE (Digital Cadastral Database - DCDB)	
0	No digital storage of Cadastral data exists
1	Graphics (in 2D) in a CAD / Graphics software, with the respective "attributes" stored in a textural database
2	The 2D graphics exist in a continuous (non-paged) storage scheme
4	The graphics and the attributes are stored within the same database & schema
5	Footprints of 3D parcels are stored in 2D, with an attribute indicating 3D
6	The 3D spatial units are stored in a separate repository
8	Link between the 3D and the 2D DCDBs (bi-directional link) exists
9	A single repository containing both 2D and 3D parcels with their full boundaries and attributes exists
10	A single repository, in LADM-compatible form, containing both 2D and 3D parcels with their full boundaries and attributes exists
SECTION 9 - PLANS OF SURVEY (INCLUDING FIELD SKETCHES)	
9a	**Definition and format**
0	No plans of survey are registered
2	There is a registered plan of survey to define all 2D spatial units (one plan can define many spatial units)
4	There is a registered plan of survey to define all 2D and 3D spatial units
6	For a 3D spatial unit, the plan contains enough information to completely define the boundaries (for all types of spatial units, but this may involve a reference to the actual building walls)
8	There exist spatial units for which the definition of the boundaries is complete without reference to a building walls or other objects
10	LADM-compatible format of survey information able to define the boundaries definitively exists
9b	**Connection between survey plans and DCDB**
0	No connection – both are maintained separately

[3] The concept is explained in Thompson et al. (2021)
[4] The concept is explained in Thompson et al. (2021)

5	DCDB contains extracted data from the survey plans, but the survey plan information is final in defining cadastral boundaries.
7	There is an automatic process to extract data from survey plans into the DCDB, but DCDB is not definitive.
10	There is automatic cross data flow between survey plans and DCDB and information in both is guaranteed.
SECTION 10 - DISSEMINATION OF 3D LAND ADMINISTRATION INFORMATION	
0	Cadastral maps are on paper form
1	Cadastral data available "in house" using network connections.
2	Spatial searches are allowed
3	Relevant software/hardware extend the availability of information dissemination
4	Multi-key access is provided (parcel identifier, house address, and other jurisdiction-specific keys)
5	Footprints of 3D parcels are depicted as 2D objects with colour or shading to indicate 3D or a 3D diagram is available through the 2D enquiry
6	The 3D spatial units are accessible to users with special software
7	3D spatial units are depicted on the 2D cadastral searches (the user doesn't need to know if a spatial unit is 2D or 3D to search for it)
10	Both the 2D and 3D spatial units are depicted on the one query mechanism.

For Section 11 – Statistic Information, no scoring is provided, but the aspects that were taken into account for the assessment and are provided through this section are:

- The number of 2D spatial units
- The number of 3D spatial units
- The population of the country/ jurisdiction
- The total surface area of the country/ jurisdiction

As presented in the Table, the rating scale ranges from 0 to 10, with 10 representing the most efficient status of a 3D LAS given the topic of the specific section, while 0 illustrates the less developed/ mature 3D LAS within this concept. Not all the scoring intervals at the various sections are the same, as this depends on the details that can be identified per topic that affect the scoring. For instance, in Section 8 regarding the DCDB, there are multiple scoring options provided, as the respective systems may significantly differentiate depending on the technical characteristics that are described at this rating scale, while for Section 7 – RRRs, less options are provided, as the alternatives can be grouped.

This assessment rubric is an initial approach to quantify the responses of the questionnaires and be able to monitor the progress of the countries that participate. Given the fact that this is developed and presented for the first time, there are some limitations that need to be addressed, specifically:

- Some questions have been changed over the years,
- Not all the responders started in the first year of the questionnaire,

- Not all the responders participate every four years at the questionnaire,
- The responders' interpretation of the questions varied from country to country according to their familiarization with the questionnaire, the terminology, their level of expertise and their wide knowledge of all the aspects that are asked within the questionnaire,
- The responders' interpretation of the questions from the same country may vary from each edition of the questionnaire, as not always the same participants respond to the questions, while at the most recent questionnaire, more participants were requested to join, aiming to involve people from both governmental organizations responsible for LA, as well as academia,
- The interpretation of the answers during the analysis varied between countries/ jurisdictions that the team analyzing them are already familiar with and can extract further info from what is answered. While, sometimes, the responses are not very clear and perhaps their interpretation from the team is not in line with the original response.
- Some of the rankings are not a simple linear score and the rankings may sometimes cross over.

3.2 Evaluation of countries using the assessment rubric for the FIG Questionnaire

Given this assessment rubric, a ranking has now been calculated for eight (8) countries over the past 4 questionnaires, spanning in total 16 years. The results are presented below, while the scores of each country in the different categories are visualised in diagrams to be able to compare the results of one country with previous questionnaires. The results from Queensland are presented in Figure 2 and it can be seen that the highest score ('10') refers to Section 6b (Title Legality), while Sections 4 (Coordinates) and 5 (Height) reach the lowest score ('2') for all the years of the questionnaires. Note that in the diagram of Figure 2 just the lines would result in overlapping lines in case no change over the years. Assuming that a county improves over the years it was decided to do a colour fill starting with the latest questionnaire (2022), first followed by the older ones drawing on top of this. In this manner it can be observed what progress was made over the years.

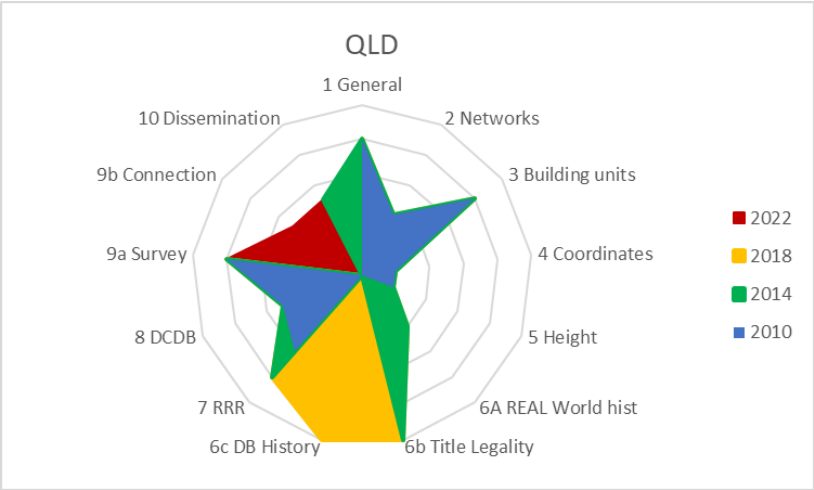

Figure 2. Queensland's (QLD) scoring in the various sections of the questionnaires, over the years.

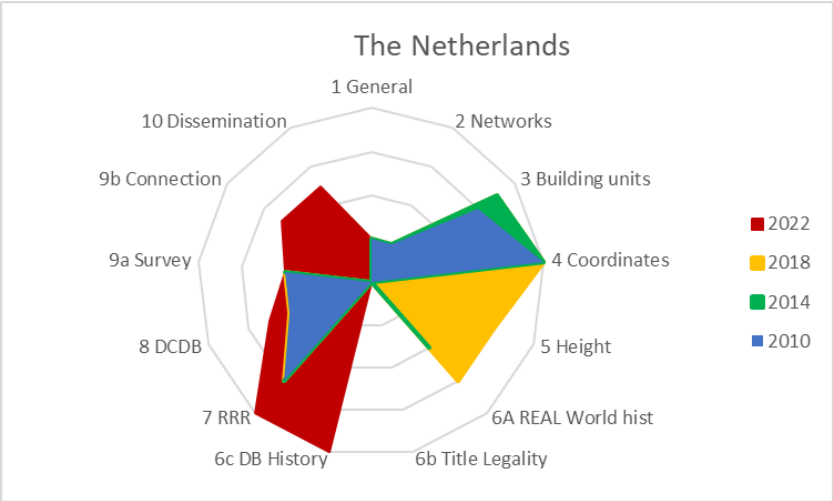

Figure 3. The Netherlands scoring in the various sections of the questionnaires, over the years.

The results from the scoring of the Netherlands for each of the sections of the questionnaire are presented in Figure 3. A spike is created for Section 6b (Title Legality) due to the fact that the scoring was '0' for the last two versions of the questionnaire that this section was completed. This makes sense as there are no titles in The Netherlands. For Section 7 (RRR) the differences on the score between the first 3 editions of the questionnaire ('6') with the higher score ('8') reached in the last questionnaire are depicted clearly in the diagram. Finally, for both countries, the Section 9b (Connection between survey plans and DCDB) is only answered in 2022 questionnaire, as it was introduced at this last edition.

What is more, for each one of the countries, a score has been given for all the sections based on the ranking scale of the rubric and the Manhattan distance is calculated. Moreover, the average of the scores is calculated. Both factors are computed for 2010, 2014, 2018 and 2022. The results are presented in the diagram depicted in Figure 4.

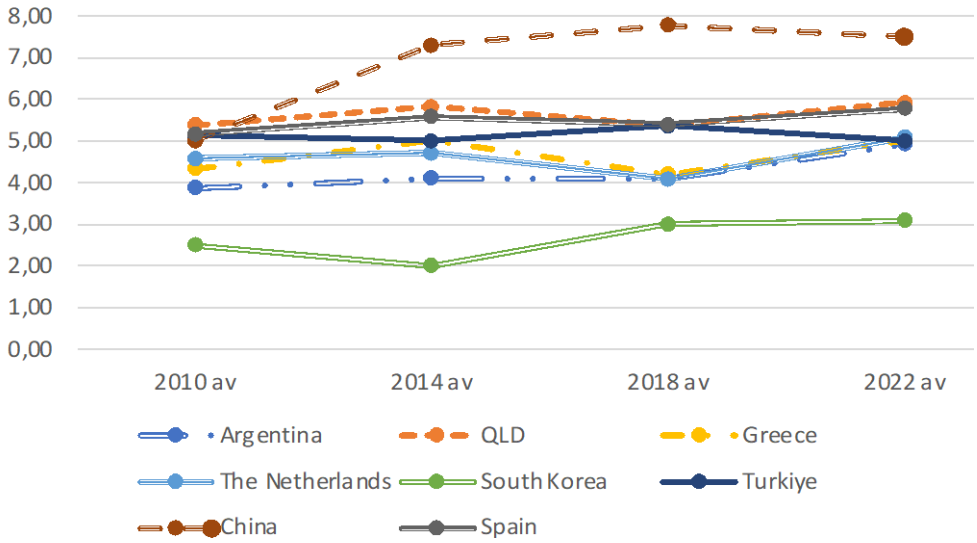

Figure 4. Total score computed for 9 countries using the rubric assessment for their responses at the four questionnaires, 2010-2022.

4. DISCUSSION AND FUTURE WORK

This paper provides follow-up of the four (4) earlier analysis papers on the FIG 3D Cadastres / Land Administration questionnaires, providing an overall idea and reflection on their advancement till now. Focus is given on the last FIG questionnaire 2022-2026 with respect to the LADM-related topics and the future trends and priorities of the countries for the coming four years, based on the initial analysis carried out by Kalogianni et al. (2023).

What is more, an assessment rubric is developed, providing a scoring of the responses in the various sections of the four (4) questionnaires. This is an initial approach to quantify the responses of the questionnaires and be able to monitor the progress of the countries that participate. Given the fact that this is developed and presented for the first time, there are some limitations that have been addressed. The evaluation is executed for eight (8) countries, leading to a score for each one of those. Given the limitations of the method, it is important to notice that the resulted ranking is based on the specific criteria developed in the paper and the responses provided by the participants and is not an official evaluation of the current LAS of the respective country.

The resulting ranking could be inspiring for countries to make more progress with regards to paying more attention or searching more the responses provided in the questionnaires (i.e. involving more experts if needed, etc.), as well as influencing the progress at national level with respect to the advances in the field of 3D LAS (if possible). What is more, this assessment rubric will initiate discussions regarding the clarity of the questions, their interpretation, the potential need to further update the questionnaire, as well as the current developments of the various aspects of 3D LAS per country.

As several new countries participated in the last edition of the questionnaire, while most of those that have participated in the previous editions still have the interest and contribute to this activity, it can be concluded that the interest on 3D Land Administration Systems worldwide is further growing and that the assessment may challenge more to participate.

The main future work directions are:

- Inform and align with countries/jurisdictions that are considering adopting LADM till 2026 or developing and LADM-based country profile (as responded in the last questionnaire) about the new developments in the context of LADM revision. It is a great opportunity as the timeline of these actions will run in parallel, given the fact that by the end of 2025 it is expected that the five first parts of LADM Edition II will be published as ISO standards.
- Work towards improving the limitations of the rubric assessment, also through consultation and open discussion with the countries that participate in this activity.
- Complete the scoring for the 19 countries/ jurisdictions that have participated in all 4 questionnaires till now, to have a more complete ranking.
- Update the next edition of the questionnaire, including the (improved) assessment rubric and request from the countries to do a self-assessment/scoring. Then, a cross-

check can be performed between the raking of the countries and the ranking of the analysis team, trying to eliminate the limitation of wrong interpretation.

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BIOGRAPHICAL NOTES

Dr. Rodney Thompson has been working in the spatial information field since 1985. He designed and led the implementation of the Queensland Digital Cadastral Data Base and is now principal advisor in spatial databases. He obtained a PhD at the Delft University of Technology in December 2007.

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